TAPHONOMIC ANALYSIS OF FISH REMAINS FROM THE MINK ISLAND SITE (XMK-030):

IMPLICATIONS FOR ZOOARCHAEOLOGICAL AND STABLE ISOTOPIC RESEARCH

By

Holly J. McKinney

RECOMMENDED:

Advisory Committee Co-Chair

Advisory Committee Co-Chair

Chair, Department of Anthropology

APPROVED:

Dean, College of Liberal Arts

Dean of the Graduate School

23 May 2013

Date

TAPHONOMIC ANALYSIS OF FISH REMAINS FROM THE MINK ISLAND SITE (XMK-030): IMPLICATIONS FOR ZOOARCHAEOLOGICAL AND STABLE ISOTOPIC RESEARCH

A

THESIS

Presented to the Faculty
of the University of Alaska Fairbanks

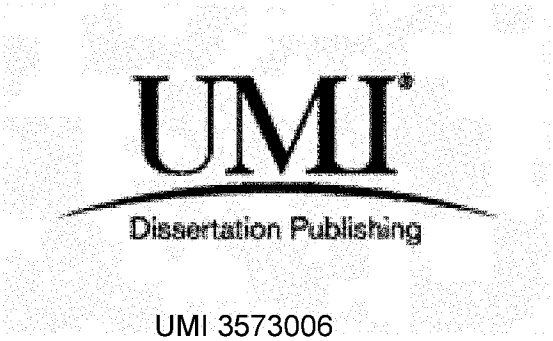
in Partial Fulfillment of the Requirements
for the Degree of

DOCTOR OF PHILOSOPHY

By

Holly J. McKinney, B.A., B.A., M.A.
Fairbanks, Alaska

May 2013



ProQuest LLC
789 East Eisenhower Parkway
P.O. Box 1346
Ann Arbor, MI 48106-1346

Abstract

This dissertation is focused on shedding the taphonomic overprint at the Mink Island site (XMK-030) to assess temporal variability of the fish bone assemblage and to establish sample selection criteria for stable isotope ($\delta^{15}N$, $\delta^{13}C$) analysis. These retrospective data may be used to identify the causes and consequences of long-term variability in local fish assemblages when combined with modern fisheries and paleo-oceanographic data. To use these data, it is essential to account for the effects of biostratinomic and diagenic agents. Inter-taxa and inter-elemental differences in bone density, shape, size, protein, and lipid content result in differing preservation and contamination potential. Without mitigating for the effects of these biostratinomic and diagenic agents, temporal changes in abundance may be skewed in favor of skeletal elements that best survive destruction. Moreover, stable isotope values may reflect differences in preservation and contamination rather than variability in ecosystem structure and function.

The results of several experiments conducted to assess preservation and contamination levels of Mink Island fish bones revealed that: 1) Preservation and contamination potential are linked with completeness percentages and burial duration, but not with bone volume density; 2) Pacific cod dentaries that are intact, unburned, and free of visible contaminants are best suited for stable isotope analysis; 3) The modified Bell pretreatment method is validated for archaeological fish bones; and 4) Because color-affecting contaminants cannot be removed without heat, color-based methods are unsuitable for assessing the cooking/burning stage of archaeological fish bones.

Interactions among humans and fishes at Mink Island were assessed using a four-stage resource depression and intensification model. The Mink Island occupants shifted their focus from small flatfishes during Stage I (7500-4500 cal. BP), to Pacific cod and sculpins during Stages II (4500-2800 cal. BP) and III (2800-900 cal. BP), to a mixture of taxa (sculpins, cods, herring, and salmon) during Stage IV (900-400 cal. BP). A decrease in Pacific cod fork lengths indicates that resource depression occurred during Stage II. Taxonomic proportion, evenness, salmon index, and skeletal element representation data demonstrate that salmon intensification did not occur during any stage at Mink Island.

Table of Contents

Page

Page

Page

Page

Page

Page

List of Figures

Page

Page

List of Tables

Page

Page

Page

Page

List of Appendices

Page

Page

Acknowledgements

Although any omissions, errors, and flaws of reasoning are my responsibility alone, it is my distinct pleasure to thank the individuals who contributed to my dissertation research. First, I would like to thank Dr. Jeanne Schaaf, Cultural Resource Manager of Katmai National Park and Preserve, for providing access to the Mink Island fish bone assemblage. I could not have completed this project without the guidance, encouragement, and funding I received from Dr. Schaaf and the National Park Service. Dr. Schaaf is a great mentor, and I am privileged to have had the opportunity to work for her.

I am also deeply indebted to my committee members, Drs. Ben Potter, Diane Hanson, Gordon Kruse, Joel Irish, and Kara Hoover, who supported my research during all stages. My co-chairs, Dr. Potter and Dr. Hanson were especially helpful, as they read several drafts and provided me with essential support and advice that improved my dissertation. Dr. Potter played a crucial role in guiding me through this process; he inspired me to step outside of my comfort zone and helped me to reach my potential. Dr. Potter helped me to see the bigger picture and introduced me to the world of modeling. I am indebted to Dr. Potter for getting me back in the field, introducing me to the Interior Alaska archaeological community, and for reminding me why I fell in love with archaeology in the first place! I could not have asked for a better advisor.

Dr. Hanson also played a critical role in guiding me through this process. She graciously provided me with laboratory space to work with the Alaska Consortium of Zooarchaeologists comparative collection at the University of Alaska Anchorage. Her passion for identifying archaeological fish bones was contagious and I have learned a great deal from her. Even though we lived in different cities, she continued to provide me with essential guidance, friendship, and support over the years. I am indebted to Dr. Hanson for introducing me to the Alaskan zooarchaeology community, and for believing in my research! From our first conversation in her lab to the last edit of this dissertation, I have considered myself fortunate to study under her direction.

Dr. Kruse read several drafts of my dissertation and helped to insure that my data was assessable to the fisheries community. Additionally, Dr. Kruse provided me with laboratory space at the School of Fisheries and Ocean Sciences (SFOS) in Juneau, where I was able to

process samples for my stable isotopic research. I enjoyed the two years I spent in Juneau, and am thankful to Dr. Kruse for supporting my research and introducing me to the SFOS community.

Dr. Irish assisted in the development of research hypotheses and answered many statistics-related questions. In addition to his assistance as a committee member, Dr. Irish provided crucial support in helping me to navigate my way through the Anthropology Program at UAF in his role as Department Chair. I appreciate his humor and wit, and it is a privilege to have had the opportunity to work with him.

Dr. Hoover supported me throughout many stages of my research, and her detailed edits helped me to develop better writing skills. Her suggestions and sound advice improved my dissertation, especially the Fish Bone Taphonomy Chapter. She inspired me to dig deeper and go farther with my research, and for that, I am deeply appreciative.

The University of Alaska Fairbanks Department of Anthropology administrative secretaries also deserve my gratitude. Karen Koziek, Charu Uppal, and Brian Green helped to smooth my passage through the Anthropology Program. I would also like to thank Dr. David Koester, the graduate student advisor, for providing guidance and support. Additionally, the School of Fisheries and Ocean Sciences (SFOS) in Juneau receives my appreciation for providing me with laboratory and office space. Lawrence Powers, Safety Officer, receives special thanks for his technical assistance. Gabrielle Hazelton, Administrative Manager for SFOS, made life easier while I was in Juneau. I would also like to thank the Alaska Consortium of Zooarchaeologists for allowing me to use their comparative collection, loaning specimens, providing me with a scholarship, and for believing in my research.

Several National Park Service employees deserve special thanks for helping me with my research. Kathryn Myers, Museum Curator for Katmai National Park and Preserve, arranged the loans of the fish faunal collection. Kathryn provided technical support during the analysis phase and helped me to locate and photograph fishing-related artifacts within the Mink Island assemblage. Her organizational skills, attention to detail, and professionalism are exemplary. Rhea Hood provided a great deal of assistance in organizing, cataloging, and photographing Mink Island fish bones. Our many insightful discussions helped me to refine my ideas concerning the role that fish played in the lives of prehistoric inhabitants along the Shelikof

Strait coast. I look forward to seeing Rhea's budding career develop, we need more fish bone specialists like her!

Dr. Carrin Halffman helped me to establish the stable isotope pretreatment protocol for use with archaeological fish bones. Our discussions in the stable isotope lab were thought provoking, and were invaluable to the completion of my dissertation. Dr. Halffman also provided critical assistance in answering numerous statistics-related questions. Her generosity and assistance cannot be overstated. I would also like to thank Bjorn Iverson for his help with sorting and cataloging the Mink Island fish bones. Bjorn was a regular companion in the laboratory and acted as a sounding board during all phases of the analysis and writing. I would like to thank my father, Allen Stelton, for his illustration skills. Allie Dewey also deserves special recognition, our regular coffee breaks kept me sane! I must also thank Dr. Maribeth Murray for her role in my dissertation research. Dr. Murray provided me with initial access to the Mink Island fish bone collection, funded a portion of my research, and taught me many life lessons.

Nicholas Sagalkin from the Alaska Department of Fish and Game Commercial Fisheries Division in Kodiak provided me with much needed fish specimens for the University of Alaska Anthropology Department comparative collection. Tony Byford and Aaron Woodrow provided additional fish specimens for my own comparative collection. I am especially appreciative of the various sculpins, rockfishes, and small flatfishes Tony and Aaron provided. To all of those individuals who were around me while I prepared fish specimens for the comparative collection, thank you for putting up with the smell!

I would also like to thank the individuals and institutions that funded my dissertation research. The zooarchaeological identification portion was funded by the National Park Service (self-generated and through Dr. Murray), National Science Foundation (through Dr. Murray), and the Center for Global Change (self-generated). Funding for the stable isotope portion of my research was self-generated and provided by the National Park Service and the Geist Fund. I received travel support for conference presentations from the Center for Global Change and the University of Alaska Department of Anthropology. The Anthropology Department and the Graduate School provided me with years of teaching assistantships, research assistantships, and fellowships. Finally, I would like to thank the Alaska Consortium of zooarchaeologists for providing me with the Christina Jensen Scholarship.

Last, but not least, I would like to thank my family and friends for their guidance and support throughout the years. I am especially thankful for the encouragement and backing I received from Lynda McKinney, you made this possible! My parents were my constant supporters and I cannot adequately express my gratitude. Finally, I am deeply indebted to my husband Mike McKinney, whose patient support and encouragement kept me on track. Mike was my rock, my counselor, and my biggest fan; I dedicate this dissertation to him.

CHAPTER 1. Introduction

Fish bones recovered from shell middens provide an archive from which subsistence strategies and technological innovations may be reconstructed (Bettinger, 1991; Binford, 1978; Fitzhugh, 1996). By incorporating the fish bone data into theoretically driven models (e.g. optimal foraging theory), it is possible to evaluate temporal changes in regional coastal hunter-gatherer foraging behaviors (Bettinger, 1991). The theoretical models may be used to test hypotheses aimed at identifying the causes of changing human foraging focus and intensity patterns (resource depression and intensification). When combined with taxonomic diversity (fish bone assemblage composition) and abundance data [number of identifiable specimens (NISP), minimum number of individuals (MNI), etc.], resource depression and intensification data may be used to reconstruct past lifeways of coastal site occupants. By comparing fish bone data from one site to fish bone data from other near-by sites, it is possible to assess regional patterns. These regional fish bone data may be compared to other regional fish bone data (e.g. Northwest Coast) to determine if patterns of human/fish use transcend regional boundaries.

Fish bones recovered from shell middens also provide a means to reconstruct temporal changes in marine ecosystem structure and function (e.g. paleoenvironmental conditions) (Hedges *et al.*, 2004). Stable nitrogen isotope ($\delta^{15}N$) values are reliable indicators of trophic levels in marine fish as ^{15}N values become enriched compared to their diets by 3.4-3.8 per mil (‰) (Dickson, 1986; Fry, 1988; Wada, 1987; Wada *et al.*, 1987). Stable carbon isotope ($\delta^{13}C$) values are indicators of primary productivity and climatic conditions as they are connected with phytoplankton abundance at the base of the food web (Fry, 1988). As productivity of phytoplankton increases, fish eat a more varied diet of lower trophic level foods (Fry, 1988; Schoeninger and DeNiro, 1984). Conversely, as productivity of phytoplankton decreases, fish specialize on fewer high trophic level foods. Therefore, $\delta^{13}C$ and $\delta^{15}N$ values are inversely related and temporal changes, if any, indicate fluctuations in marine ecosystem structure and function (Fry, 1988).

However, before using archaeological fish bone data to answer cultural and paleoenvironmental research questions, it is necessary to account for the ways that

biostratinomic (cooking, burning, cut marks, breakage, etc.) and diagenic (physical, chemical, and biological) agents degraded and contaminated the bones. Biostratinomic agents affect bones before burial, whereas diagenic agents affect bones after burial within an archaeological context (Lyman, 1994). Without mitigating for the effects of biostratinomic and diagenic agents, zooarchaeological abundance measures and stable isotope values may be affected by inter-taxa and inter-skeletal element differences in preservation and contamination potential (Butler and Chatters, 1994; Nicholson, 1996a; Smith, 2008).

Several of the hypotheses tested in this dissertation are aimed at establishing the preservation and contamination biases of the Mink Island (XMK-030) fish bone assemblages (Upper Midden, Lower Midden, House Feature 5). Because this research is focused specifically on fish bones, the results infill gaps in the zooarchaeological and stable isotopic literature. Previous preservation and contamination evaluations have concentrated on mammal bones (e.g. Ambrose, 1990; Hedges et al., 2004; Kennedy, 1988; van Klinken and Mook, 1990), and relatively little is known about fish bones (Petchey and Higham, 2000). Because fish bones possess a different structural (mineralization, collagen fibril packing, and bone volume density) and chemical (amino acid sequence, lipid content, and protein content) composition compared to mammal bones, biostratinomic and diagenic agents affect them differently (Szpak, 2011). Fish bones are less able to withstand the effects of biostratinomic and diagenic agents (Nicholson, 1996a). Therefore, fish bones become too fragmentary to identify faster than mammal bones, which causes them to be underrepresented within zooarchaeological assemblages (Lyman and O'Brien, 1987). Moreover, fish bones tend to be more contaminated and degraded than their mammalian counterparts, and need to be treated differently throughout all stages of stable isotope analysis (e.g. sample selection, pretreatment, quality control assessment) (Szpak, 2011).

This research uses the Mink Island preservation and contamination assessment data to establish sample selection criteria for Pacific cod (*Gadus macrocephalus*) skeletal elements for stable isotopic analysis. This study also validates the modified Bell *et al.* (2001) stable isotope pretreatment method for use with archaeological fish bones. Additionally, the amino acid sequence of Atlantic cod (*Gadus morhua*) is used to develop stable isotope quality control indicator values that account for the distinct chemical composition of cold-water-adapted fishes.

These data are critical to local and non-local researchers attempting to reconstruct ecosystem structure function using archaeological fish bones.

This investigation also identifies many of the variables (e.g. bone volume density, shape, and robusticity) responsible for structuring the Mink Island fish bone assemblage. Inter-taxa and inter-skeletal element differences in preservation potential are also explored. The results are used to refine abundance measures, which account for differential fragmentation [minimum number of elements (MNE) and minimum number of individuals (MNI)] at Mink Island. These data have implications for local and non-local fish bone researchers at all stages of planning, excavation, and analysis (e.g. sampling, sieving, and assessing abundance).

Site Location

Alaska's geographic location and archaeological potential are unmatched and provide numerous opportunities to explore a variety of current topics (e.g. settlement patterns, subsistence strategies, technological innovations, etc.) in archaeology (e.g. Bettinger, 1991; Binford, 1978; Fitzhugh, 1996). An essential aspect of Alaskan archaeology is the ability to examine the relationships between settlement patterns, subsistence strategies, and technological innovations during periods of climate change. These relationships are especially important in Arctic and Subarctic regions that are positioned in dynamic areas (e.g. on the coast, near subduction zones, near glaciers, etc.). Dynamic areas are often the first to feel the effects of climate change, and therefore, are often the first to display evidence of cultural changes. Because the Mink Island site is in a dynamic area, it provides a unique opportunity to explore the relationship between culture and climate change in Subarctic Alaska.

The Mink Island site is on a small island off the coast of the Alaska Peninsula that is devoid of trees, which left the occupants exposed to the storms that regularly hit the region (Hilton, 2002). Because Mink Island is near the Pacific Plate/North American Plate subduction zone, volcanic eruptions, ash falls, earthquakes, tsunamis, and rising sea levels also periodically affected the occupants (Crowell and Mann, 1996; Hood, 1986; Pflacker and Berg, 1994a; Riehle, 2002). One may ask why the Mink Island occupants would have settled on the small and exposed island. The reason is likely linked to the abundant resources that were readily

available. The Mink Island site is near abundant sea mammal (rookeries, haul-outs, and travel corridors), fish (marine and riverine), shellfish (intertidal), bird (seabirds and waterfowl), and driftwood (fuel, tools) resources (Crowell *et al.*, 2003; Fitzhugh, 1996; Hilton, 2002).

Mink Island's close proximity to diverse habitats afforded the occupants year-round access to abundant resources. During the relatively warm and calm months, the occupants would have spread out and used boats to access nearshore marine and riverine resource habitats, where they obtained numerous and diverse taxa (e.g. sea mammals, birds, and fishes) (Crowell and Mann, 1996; Fitzhugh, 1996). During the relatively cool and stormy months, when boat travel was dangerous or prohibitive, the occupants typically resided in small villages where they maintained access to abundant resources (e.g. shellfish, nearshore marine fishes, and driftwood) from shore (Crowell *et al.*, 2003). Therefore, the cost benefits of regular exposure to stormy conditions and periodic exposure to catastrophic events (e.g. volcanic eruptions, earthquakes, tsunamis, rising sea levels, etc.) were outweighed by access to abundant resources available year-round.

Because the Mink Island site is close to the coastal margin, the occupants felt the impacts of adverse conditions (e.g. stormy weather, rising sea levels, etc.) relatively quickly after climatic changes. The Mink Island site was abandoned at least two times over the past few millennia (Hilton, 2002; Schaaf, 2009). There is an occupational hiatus at the site between 4100 and 2000 calibrated radiocarbon years BP (cal. BP), which roughly corresponds to the Neoglacial period (a period of cool and stormy conditions) (Crockford and Frederick, 2007; Hilton, 2002). Additionally, the Mink Island site was abandoned sometime after 455 cal. BP, which roughly corresponds to the initiation of the Little Ice Age, another cool and stormy period (Solomon *et al.*, 2007). The Mink Island occupants likely used other locations in Amalik Bay throughout the span of time Mink Island was occupied and during the periods it appears to have been abandoned (Schaaf, personal communication, 2011). The settlement patterns suggest that the Mink Island site was a preferred habitation location during all but the coolest and wettest periods over the past few millennia.

Changing Lifeways

In addition to providing data about prehistoric settlement patterns, the Mink Island site provides critical data related to changing subsistence strategies. Using zooarchaeological abundance measures [e.g. NISP, MNE, MNI, minimum animal units (MAU), etc.], it is possible to document changes in taxonomic composition in relation to climate changes at Mink Island (Lyman, 1994). For example, an increase in the ratio of cold-water-adapted fish taxa (e.g. yellow Irish lords, herring, etc.) compared to warm-water-adapted fish taxa (e.g. Pacific cod, walleye pollock, halibut, etc.) may be used to infer a decrease in sea surface temperatures (Anderson and Piatt, 1999). Additionally, a reduction in Pacific cod fork lengths (as inferred via linear regression analysis) may be used to infer a decrease in sea surface temperatures (e.g. Anderson and Piatt, 1999; Orchard, 2003). If climate change can be ruled out as a causal factor, these changes in taxonomic representation and fork length data may be used to make inferences about how humans interacted with fishes at Mink Island.

The appearance of technological innovations provides another means to link cultural change with climate change. The advent of technological innovations (e.g. nets, weirs, storage pits, drying racks, ulus, etc.) that correspond to a shift in subsistence strategy focused on salmon (*Oncorhynchus* spp.) is one such example. This subsistence strategy shift corresponded with the cool and stormy climatic conditions associated with the Neoglacial period (e.g. Kachemak tradition). The strategy shift was only possible after the advent of technological innovations, which lowered procurement costs and made the new strategy profitable (Partlow, 2000). The advent of technological innovations occurred after the impacts of cooler and stormier conditions made it more difficult to travel by boat to obtain food resources (Fitzhugh, 1996; Kopperl, 2003). Through technological innovations, the prehistoric occupants limited their exposure to dangerous conditions and focused their procurement efforts on salmon resources that were captured during the warm months from relatively safe riverine environments. Technological innovations provided the means to capture large numbers of salmon that could be easily processed and stored for later consumption (Partlow, 2000). Shifts in subsistence strategies are usually linked with shifts in technological innovations, and therefore, should be examined concurrently.

After the impacts of climate change on settlement patterns, subsistence strategies, and technological innovations have been identified and documented, it is possible to make inferences about changing human lifeways within the region. The natural constraints of the archaeological record (e.g. sea level rise, tsunamis, earthquakes, acidic soil) make deeply buried, stratified sites with cultural features rare within the region. Organic preservation (wood, bone, ivory, etc.) is often lacking (because of acidic soil), and post-depositional disturbances (e.g. turbation) are common. Because the Mink Island site is highly stratified, has multiple components, contains excellent organic preservation, and is the oldest site on the Shelikof Strait coast; it is highly significant (Schaaf, 2009). With so few excavated sites in the region with good faunal preservation and a high level of stratification, it is difficult to draw conclusions about past human lifeways. Until more research is completed along the Shelikof Strait coast, the Mink Island site, together with the sites within the Amalik Bay National Historic Landmark District, provides the best opportunity to evaluate how prehistoric lifeways of the regional occupants have changed over time.

Problem Domain

Because fish bones recovered from shell middens are an archive of stable isotope conditions, they provide a way for marine ecologists to reconstruct changes in past marine ecosystem structure and function (Hedges *et al.*, 2004). Bones are especially useful for these paleoenvironmental reconstructions because they provide more biologically averaged values than plants, and therefore, the signal is less noisy (Hedges *et al.*, 2004). Fish bones may also be used to test theoretically driven models to evaluate change over time in coastal hunter-gatherer foraging behaviors (Bettinger, 1991). Human impacts (e.g. biostratinomic agents) on fish populations may be differentiated from environmental impacts (e.g. diagenic agents) by comparing archaeological fish bone data to proxy paleoenvironmental data (e.g. ice cores, sediment cores, tree rings, glacial histories, etc.) and cultural data (e.g. artifacts, features, other faunal data, etc.) (Kopperl, 2003). Fish faunal data provide critical evidence from which food choices, procurement strategies, preparation strategies (e.g. cooking and processing for

storage), and site occupation seasonality may be reconstructed (Kopperl, 2003; Nicholson, 1996a; Partlow, 2000).

However, before using archaeological fish bone data to answer cultural and paleoenvironmental research questions, it is necessary to account for the effects of biostratinomic and diagenic agents (Nicholson, 1996a, 1998; Richter, 1986; Shipman *et al.*, 1984; Steiner *et al.*, 1995). Biostratinomically altered bone are less able to withstand the effects of diagenic agents, and therefore, are often underrepresented in the archaeological record. Intrinsic (bone size, porosity, chemical structure, and molecular composition) and extrinsic (pH, temperature, moisture content, and microbial action) factors control the rate at which a bone undergoes diagenesis (Child, 1995a; Hedges, 2002; Linse, 1992; Lyman, 1994; Von Endt and Ortner, 1984). Intrinsic differences result in inter-taxa and inter-skeletal element variability in preservation and contamination potential. Without mitigating for the effects of biostratinomic and diagenic agents, temporal changes in abundance may be skewed in favor of those skeletal elements that best survive destruction (Butler and Chatters, 1994; Nicholson, 1996a; Smith, 2008). Moreover, stable isotope ($\delta^{13}C$, $\delta^{15}N$) values may reflect differences in preservation and contamination rather than variability in ecosystem structure and function (Hedges *et al.*, 2004; Lyman, 1994; Stafford *et al.*, 1988; van Klinken, 1999; Wilson and Pollard, 2002).

This research is divided into two sections: 1) Evaluating the effects of taphonomic agents (biostratinomic and diagenic) on fish bones recovered from the Mink Island site, and 2) Exploring temporal changes in interactions among humans and fishes at Mink Island. Taphonomic agent action is evaluated in Chapters 6 and 7. Interactions among humans and fishes are explored in Chapter 8.

Zooarchaeological methods are used in Chapter 6 to identify the effects of biostratinomic agents (e.g. processing for storage) on a sample of Pacific cod and salmon skeletal elements. Skeletal element abundance values (e.g. NISP, MNE, and %MAU) are compared to bone volume density (BVD) values to determine if the densest skeletal elements are most numerous. If the densest skeletal elements are most abundant, diagenic agents (e.g. density mediated attrition) are primarily responsible for structuring the assemblages. Conversely, if the least dense skeletal elements are most abundant, biostratinomic agents (e.g. processing for storage) are primarily responsible for structuring the assemblages.

Zooarchaeological methods are also used in Chapter 6 to identify the effects of diagenic agents (e.g. fragmentation) on the Mink Island fish bone assemblages. The objective is to determine which factors affected preservation potential (as assessed by mean completeness percentage values) of the fish bones. Mean completeness percentage (%) values of the fish bones are compared to radiocarbon years BP, taxonomic groupings (family-level), anatomical regions (non-vertebral), robusticity categories (robust vs. non-robust), and shape categories (compact, intermediate, and elongated) to identify causal factors. By identifying significant correlations, it is possible to determine the factor/s responsible for structuring the Mink Island fish bone assemblage. The Mink Island data can be used to guide future research aimed at calculating the abundance of fish bones recovered from regional shell midden contexts.

Stable isotopic methods are used in Chapter 7 to measure the effects of biostratinomic (cooking/burning) and diagenic agents (preservation and contamination) on a sample of 72 ancient (Mink Island) and 31 modern (Gulf of Alaska) Pacific cod skeletal elements. The effects of biostratinomic agents are explored by determining if color-affecting contaminates can be removed from the Mink Island samples so that Petchey and Higham's (2000) method may be used to assess the cooking/burning stage. If the color-affecting contaminates cannot be removed, other methods (e.g. scanning electron microscope and x-ray diffraction) are better suited to assess the cooking/burning stage of bones recovered from archaeological contexts.

Stable isotopic methods are also employed in Chapter 7 to measure the effects of diagenic agents on the same sample of 72 Pacific cod bones recovered from Mink Island. The 31 modern Pacific cod bones provide baseline preservation and contamination values to which the Mink Island values are compared. Preservation is established using the following indicators: physical appearance class, bulk bone % nitrogen (BB%N), bulk bone % carbon (BB%C), and % collagen yield. Preservation indicator values of the Pacific cod samples are compared to BVD, mean completeness %, and radiocarbon years BP to determine if significant differences in preservation exist among the three groups. The objective is to identify the factors that affect preservation potential at Mink Island.

The same Mink Island Pacific cod samples are used to assess contamination potential, which is assessed by subtracting the expected BB%C value from the actual BB%C value (expected values are derived from the 31 modern Pacific cod samples). The difference between

the expected and the actual BB%C value is used to quantify the level of carbon-rich contaminates that entered the bone from the burial environment. Carbon contamination is compared to BVD, mean completeness %, and radiocarbon years BP to determine if significant differences in contamination exist among the three groups.

The preservation and contamination evaluation results are used to identify the Pacific cod skeletal element best suited for stable isotope analysis. The skeletal element with the lowest average preservation (BVD, physical appearance class, BB%N, BB%C, % collagen yield) and contamination (actual versus expected BB%C) ranking is selected for analysis. Additionally, cold-water-fish-specific stable isotope quality control indicators [% carbon (C) by weight, % nitrogen (N) by weight, and atomic C: N] are used to assess the quality of individual stable isotope values. The quality control indicator values are used to validate the modified Bell *et al.* (2001) stable isotope pretreatment method for use with archaeological fish bones.

Interactions among humans and fishes at Mink Island are explored using zooarchaeological methods in Chapter 8. Interactions are assessed using a four-stage resource depression and intensification model derived from optimal foraging theory (e.g. Fitzhugh, 1996; Kopperl, 2003; Partlow, 2000). The model evaluates potential ways that social organization changed over time at Mink Island. One component explores how taxonomic diversity and abundance changed in relation to the four stages of the resource model. A second component uses changing age structure data (e.g. fork lengths) to determine if evidence for resource depression is present at Mink Island. The third component uses taxonomic proportion, evenness, and skeletal element representation data to explore evidence of resource intensification of salmon. The Mink Island fish bone abundance data are also compared to fish bone abundance data from two regional archaeological sites, Rice Ridge and Settlement Point, to identify potential regional connections.

Concluding remarks integrate the data from Chapters 6-8 to identify the factors that affect preservation and contamination potential of fish bones in shell midden contexts. The preservation and contamination conclusions are used to refine methods for completing zooarchaeological (recovery, sieving, and analysis) and stable isotopic (sample selection, pretreatment, quality control) research on archaeological fish bone samples.

Broader Implications

This research has important implications for fisheries managers, marine ecologists, taphonomists, and zooarchaeologists. The methods-focused taphonomic analysis is essential to researchers conducting zooarchaeological and stable isotopic analysis on archaeological fish bones. This research identifies fish bone-specific preservation and contamination biases that affect abundance calculations and stable isotope values. The theoretically focused zooarchaeological analysis is critical to researchers applying resource depression and intensification models to fish bones within the Shelikof Strait region.

Archaeological fish bones are important to fisheries managers because they possess a greater time depth as compared to datasets typically available to researchers (e.g. millennial versus decadal scale). The extended time-depth provides additional data from which new baselines of species distribution and abundance may be formed (Ojaveer and MacKenzie, 2007). By documenting which species lived when and where, problems associated with the shifting baseline syndrome may be avoided (Jackson et al., 2001; Myers and Worm, 2003; Pauly, 1995; Pinnegar and Engelhard, 2008). These analyses, therefore, help stakeholders develop recovery and long-term management plans for fish populations and marine ecosystems (Ojaveer and MacKenzie, 2007).

This research also augments taphonomic analyses that aim to establish preservation potential of archaeological fish bones (e.g. Butler, 1990; Butler and Chatters, 1994; Nicholson, 1992a, 1996a, 1998; Smith, 2008). The preservation potential data may be used to refine abundance values of fish bones recovered from shell middens. Without completing taphonomic analysis before measuring abundance, the results may be skewed in favor of those skeletal elements that best survive destruction by biostratinomic and diagenic agents. Because fish bones tend to be smaller and more fragmented compared to other animal classes (e.g. mammals and birds), it is especially important to complete taphonomic analysis before interpreting abundance measure results. Additionally, this research establishes that taxonomic richness and evenness are affected by mesh sieve sizes, and smaller mesh sizes (e.g. 0.32 cm or 1/8 in) are preferred.

This research enhances stable isotopic analysis, which aims to reconstruct ecosystem structure and function using archaeological fish bones (e.g. Misarti, 2007; Misarti *et al.*, 2009) by establishing quality control indicator values that have been adjusted to account for the chemical and structural differences of fishes (e.g. Ambrose, 1993; Kennedy, 1988; Szpak, 2011; van Klinken, 1999; van Klinken and Hedges, 1995). The adjusted quality control indicator values are also used to decide if the Bell *et al.* (2001) stable isotope pretreatment method is gentle enough for use with archaeological fish bones. Preservation and contamination evaluation data are used to determine which Pacific cod skeletal element is best suited for stable isotope analysis.

This research enhances a National Park Service project that combines chronological (Hilton, 2002; Schaaf, 2009), sedimentological (Hilton, 2002; Laybolt, 2002), zooarchaeological (Casperson, 2009; Iverson, in prep; Murray, 2004a, 2004b; Strathe, 2009), and lithic (Tennessen, 2009) analyses to understand the history of human occupation at the Mink Island site. The Mink Island fish bone data is also relevant to research projects, which use faunal assemblage abundance values to draw region-wide patterns of culture change (Hausler-Knecht, 1991, 1993; Kopperl, 2003; Partlow, 2000).

CHAPTER 2. Research Design and Methods

Introduction

Fish bones are structurally and chemically different from mammal and bird bones (Szpak, 2011); as a result, they tend to be less well preserved in archaeological contexts (Chapter 5). Sieving strategies and abundance measures must be adjusted to accommodate preservation differences when working with fish bone assemblages. Without mitigating for differences at all stages (i.e. planning, excavating, analyzing, and interpreting), abundance measures may be skewed in favor of those skeletal elements that best survive biostratinomic and diagenic destruction.

The sieving strategies and abundance measures presented here account for the structural and chemical differences of fish bones in an attempt to overcome the preservation biases. Biases are established via taphonomic analysis, during which zooarchaeological and stable isotopic methods are used to assess the Mink Island fish bone assemblage. The information derived from the taphonomic analysis is then used to guide interpretations of fish bone abundance. The abundance data are used to infer temporal changes in interactions among humans and fishes at Mink Island.

The research questions are divided into three groups, the first two (A and B) establish the taphonomic preservation and contamination of Mink Island fish remains; the third group (C) explores the interactions among humans and fishes at Mink Island. Group A contains two research questions that use zooarchaeological methods to establish inter-taxa and inter-skeletal elemental differences in preservation potential. Group B contains two research questions that use stable isotopic methods to establish which factors affect the preservation and contamination potential of a sample of modern and Mink Island Pacific cod bones. Additionally, group B contains a research question that uses stable isotopic methods to determine if color-affecting contaminants may be removed from archaeological fish bones so the cooking/burning stage may be assed using color-based methods. Group C contains three research questions that use zooarchaeological methods to test a four-stage resource depression and intensification model. The data are used to determine if Mink Island occupants targeted specific fish taxa, and

if so, if that changed over time. Fish bone abundance values from the Mink Island site are also compared to abundance values from two other sites in the area (e.g. Rice Ridge and Settlement Point) to establish regional connections.

The zooarchaeological and statistical methods used to answer the specific research questions are presented following the null and alternate hypothesis. The methods are presented in bullet form, descriptions that are more detailed are found within Chapters 6-8. The zooarchaeological methods outline the ways that fish bone abundance was estimated using established measures (e.g. NISP, MNE, MNI, MAU, etc.). The methods employed to test the null and alternate hypotheses are presented in the statistical methods section.

The laboratory methods that were used to analyze the Mink Island fish bone assemblage are also described. Definitions of the abundance measures (e.g. NISP, MNE, MNI, MAU, etc.) used to quantify the assemblage are included. Method adjustments, if any, which accommodate for the structural and chemical differences of fish bones, are described. Fish-specific methods, which are used to determine fish length from specific skeletal elements, season of death, and age of death, are also presented.

Research Questions, Hypotheses, and Methods

Group A. Taphonomic Analysis Using Zooarchaeological Methods

Research Question 1: Did inter-taxa and inter-skeletal element differences in bone volume density (BVD) structure the Mink Island fish bone assemblage? Is there a significant correlation between BVD and abundance (%MAU) among Pacific cod and Pacific salmon skeletal elements from temporal/cultural zones UM I, UM II, UM III, LM I, and LM II?

Null Hypothesis 1a: There is not a significant correlation between BVD and abundance (%MAU) among Pacific cod skeletal elements from temporal/cultural zones UM I, UM II, UM III, LM I, and LM II. H_o: $p \geq .05$

Null Hypothesis 1b: There is not a significant correlation between BVD and abundance (%MAU) among Pacific salmon skeletal elements from temporal/cultural zones UM I, UM II, UM III, LM I, and LM II. H_o: $p \geq .05$

Alternate Hypothesis 1a: There is a significant correlation between BVD and abundance (%MAU) among Pacific cod skeletal elements from temporal/cultural zones UM I, UM II, UM III, LM I, and LM II. H_a: $p < .05$

Alternate Hypothesis 1b: There is a significant correlation between BVD and abundance (%MAU) among Pacific salmon skeletal elements from temporal/cultural zones UM I, UM II, UM III, LM I, and LM II. H_a: $p < .05$

Zooarchaeological Methods 1:

a. Select all Pacific cod (*Gadus macrocephalus*) and Pacific salmon (*Oncorhynchus* spp.) skeletal elements with known BVD for analysis.

b. Create a separate BVD database containing the following information: temporal/cultural zone, taxon, skeletal element, side, and completeness %.

c. Determine NISP values for each taxon and temporal/cultural zone by counting the number of complete and fragmentary skeletal elements.

d. Determine MNE values for each taxon and zone using complete or fragmentary skeletal elements with non-repetitive landmarks. Skeletal element side, size, and completeness % estimates are used to refine MNE values.

e. Determine MAU values for each taxon and zone by dividing MNE values by the number of times that a skeletal element occurs within an individual. Average numbers of Pacific cod and sockeye salmon (*Oncorhynchus nerka*) vertebrae were obtained from Mecklenburg *et al.* (2002).

f. Determine skeletal element representation (%MAU) for each taxon and zone by dividing MAU values by the highest MAU value within the assemblage.

Statistical Methods 1:

a. Compare BVD values to %MAU values using Spearman's rho and Kendall's tau-b to determine if the densest bones are the most numerous bones.

b. Reject the null hypothesis 1a if the Pacific cod skeletal elements with the highest BVD values (e.g. dentary, maxilla, and vomer) possess the highest %MAU values.

c. Reject the null hypothesis 1b if the Pacific salmon skeletal elements with the highest BVD values (e.g. vertebra, articular, maxilla) possess the highest %MAU values.

Research Question 2: Are there temporal, inter-taxa, and inter-skeletal element differences in Mink Island fish bone completeness % values? To what extent did the length of time the bones were associated with the burial context, taxonomic groupings, anatomical regions, robusticity categories, and shape categories affect completeness % values?

Null Hypothesis 2a: Completeness % values did not differ significantly among temporal/cultural zones. H_o: $p \geq .05$

Null Hypothesis 2b: Completeness % values did not differ significantly among taxonomic groupings. H_o: $p \geq .05$

Null Hypothesis 2c: Completeness % values did not differ significantly among anatomical regions. H_o: $p \geq .05$

Null Hypothesis 2d: Completeness % values did not differ significantly among robusticity categories. H_o: $p \geq .05$

Null Hypothesis 2e: Completeness % values did not differ significantly among shape categories. H_o: $p \geq .05$

Alternate Hypothesis 2a: Completeness % values differed significantly among temporal/cultural zones. H_a: $p<.05$

Alternate Hypothesis 2b: Completeness % values differed significantly among taxonomic groupings. H_a: $p<.05$

Alternate Hypothesis 2c: Completeness % values differed significantly among anatomical regions. H_a: $p<.05$

Alternate Hypothesis 2d: Completeness % values differed significantly among robusticity categories. H_a: $p<.05$

Alternate Hypothesis 2e: Completeness % values differed significantly among shape categories. H_a: $p<.05$

Zooarchaeological Methods 2:

a. Determine NISP values of Mink Island fish vertebrae, non-vertebrae, and bones that are too fragmentary to identify beyond class for each temporal/cultural zone.

b. Compile percent NISP (%NISP) values by dividing the number of bones from a specific category (i.e. vertebrae) by the total number of bones from a temporal/cultural zone and multiplying the quotient by 100.

c. Organize the Mink Island fish bones by taxa (family-level), anatomical region, robusticity (presence or absence), and shape (elongated, intermediate, compact) categories.

Statistical Methods 2:

a. Use Pearson product-moment correlation coefficients to assess the relationship between the temporal/cultural zones and the %NISP values of vertebrae, non-vertebrae, and skeletal elements that are too fragmentary to identify beyond class.

b. Use Pearson product-moment correlation coefficients to evaluate the relationship between the temporal/cultural zones and mean completeness % values of Mink Island fish remains.

c. Use one-way ANOVA to assess differences in mean completeness % of Mink Island skeletal elements aggregated by family-level taxonomic groupings.

d. Use one-way ANOVA to evaluate the relationship between mean completeness % and anatomical regions.

e. Use an independent-samples t-test to evaluate the relationship between completeness % of robust and non-robust skeletal elements.

f. Use one-way ANOVA to compare completeness percentages of compact (width to length % >66.67%), intermediate (width to length % =33.34%-66.66%), and elongated (width to length %< 33.33%) skeletal elements to ascertain if skeletal element shape (2-dimensional) plays a significant role in determining fish bone completeness percentages.

g. If there are temporal, inter-taxonomic (family-level taxa), and inter-skeletal element (anatomical regions, robusticity, and shape) differences in mean completeness %, the null hypotheses may be rejected.

Group B. Taphonomic Analysis Using Stable Isotopic Methods

Research Question 3: Is it possible to remove color-affecting contaminants (e.g. humic acids, fulvic acids, and humins) from Pacific cod skeletal elements recovered from the Mink Island site so that the cooking/burning stage may be assessed using Petchey and Higham's (2000) method?

Null Hypothesis 3: Color-affecting contaminants cannot be removed from Pacific cod skeletal elements recovered from the Mink Island site, so the cooking/burning stage cannot be assessed using Petchey and Higham's (2000) method. H_0: Munsell (1954) colors do not match Petchey and Higham's (2000).

Alternate Hypothesis 3: Color-affecting contaminants can be removed from Pacific cod skeletal elements recovered from the Mink Island site, so the cooking/burning stage can be assessed using Petchey and Higham's (2000) method. H_a: Munsell (1954) colors match Petchey and Higham's (2000).

Methods 3:

a. Powder Pacific cod bone samples (<63μm) using a ball mill.

b. Assign Munsell (1954) color to the powdered Pacific cod bone.

c. Compare with burning stage (class I to V) as established by Petchey and Higham (2000).

d. Apply NaOH wash to the powdered bone samples to remove humic acids.

e. Reassign Munsell (1954) color and reassess burning stage.

f. Apply HCl wash to the powdered bone samples to remove fulvic acids.

g. Reassign Munsell (1954) color and reassess cooking/burning stage.

h. If cooking/burning stage of Mink Island Pacific cod bones may be determined using Petchey and Higham's (2000) method, the null hypothesis may be rejected.

Research Question 4: Is the Pacific cod dentary the best preserved (physical appearance, BB%N, BB%C, and % collagen yield) and least contaminated (expected versus actual BB%C) skeletal element (possess the lowest average ranking), and therefore the most appropriate skeletal element to use for stable isotope ($\delta^{13}C$, $\delta^{15}N$) analysis?

Null Hypothesis 4: Pacific cod dentaries do not possess the lowest average preservation/contamination ranking, and therefore, they are not suitable for stable isotope analysis. H_o: $p \geq .05$

Alternate Hypothesis 4: Pacific cod dentaries possess the lowest average preservation/contamination ranking, and therefore, they are suitable for stable isotope analysis. H_a: $p < .05$

Zooarchaeological Methods 4:

a. Assess the physical appearance of Mink Island skeletal elements using Petchey and Higham's (2000) method.

b. Clean, dry, powder, and submit the Mink Island Pacific cod samples to the Alaska Stable Isotope Facility for BB%N and BB%C analysis.

c. Determine % collagen yield of the samples by dividing the post-treatment sample weight by the sample weight and multiplying the quotient by 100.

d. Use linear regression analysis on a sample of modern Pacific cod bones to establish a formula to determine expected BB%C values from actual BB%N values [BB%C = (BB%N x 2.2528) + 1.478)].

e. Subtract expected BB%C values from actual Mink Island BB%C values to obtain proxy contamination values.

f. Rank (1-6) the Mink Island skeletal elements based on preservation (NISP, BVD, mean completeness %, BB%N, and BB%C) and contamination (actual minus expected BB%C) values. The skeletal element that is best preserved and least contaminated will possess the lowest averaged ranking.

g. Use the averaged ranking data to determine which Mink Island skeletal element is best suited for stable isotope analysis.

Statistical Methods 4:

a. Use chi-square statistical analysis to determine if significant differences in physical appearance [as assessed using Petchey and Higham's (2000) method] exist among BVD, mean completeness %, and radiocarbon years BP categories.

b. Use one-way ANOVA statistical analysis to determine if significant differences in BB%N, BB%C, % collagen yield, and carbon contamination values exist among BVD, mean completeness %, and radiocarbon years BP categories.

c. If the preservation and contamination assessments indicate that the dentary is the best preserved and least contaminated, the null hypotheses may be rejected.

Research Question 5: Do quality control indicators (% collagen yield, %C by weight, %N by weight, and atomic C: N) validate the modified Bell *et al.* (2001) method for archaeological fish bones?

Null Hypothesis 5a: Quality control indicators (% collagen yield, %C by weight, %N by weight, and atomic C: N) do not validate the modified Bell *et al.* (2001) method for archaeological fish bones. H_o: $P \geq .05$

Alternate Hypothesis 5: Quality control indicators (% collagen yield, %C by weight, %N by weight, and atomic C: N) validate the modified Bell *et al.* (2001) method for archaeological fish bones. H_a: $p < .05$

Zooarchaeological Methods 5:

a. Use the modified Bell *et al.* (2001) pretreatment methods to prepare Mink Island Pacific cod bones for stable isotope analysis (Appendix A).

b. Submit samples to the Alaska Stable Isotope Facility for $\delta^{13}C$ and $\delta^{15}N$ analysis.

n. Assess quality of $\delta^{13}C$ and $\delta^{15}N$ values using multiple indicators (% collagen yield, % C by weight, % N by weight, and atomic C: N).

Statistical Methods 5:

a. Use one-way ANOVA statistical analysis to determine if significant differences in % collagen yield, % C by weight, %N by weight, and atomic C: N values exist among BVD, mean completeness %, and radiocarbon years BP categories.

b. If the $\delta^{13}C$ and $\delta^{15}N$ values of the Mink Island samples meet quality control standards, the null hypothesis may be rejected.

Group C. Interactions among Humans and Fishes at Mink Island

Research Question 6: Did Mink Island occupants target specific fish taxa, and if so, did those taxa vary in relation to season, climate zones, and procurement methods?

Null Hypothesis 6 (assessed qualitatively): Mink Island occupants did not target specific fish taxa and those taxa did not vary in relation to season, climate zones, and procurement methods.

Methods 6:

a. Sort fish by skeletal element, taxon, temporal/cultural zone, and model stage.

b. Use %NISP and %MNI to compare taxa-specific changes in abundance over time.

c. Compare %NISP results to seasonality index, climate zones, and model stages.

Research Question 7: Is there evidence of resource depression(s) at Mink Island, as indicated by a reduction in Pacific cod fork lengths, and if so, is climate a forcing mechanism?

Null Hypothesis 7a: Fork lengths do not differ significantly among temporal/cultural zones. H_o: $p \geq .05$

Null Hypothesis 7b: Fork lengths do not differ significantly among climate zones. H_o: $p \geq .05$

Alternate Hypothesis 7a: Fork lengths differ significantly among temporal/cultural zones. H_a: $p < .05$

Alternate Hypothesis 7b: Fork lengths differ significantly among climate zones. H_a: $p < .05$

Zooarchaeological Methods 7:

a. Sort fish by skeletal element, taxon, temporal/cultural zone, and model stage.

b. Use the single regression method used by Orchard (2003) to estimate fork length of Pacific cod from the #3 quadrate measurement.

c. Compare fork length data to proxy climatic data (e.g. Heusser *et al.*, 1985; *Solomon et al.*, 2007) to determine if fork lengths vary with climate zones.

Statistical Methods 7:

a. Use one-way ANOVA statistical analysis to determine if there are significant differences in mean fork lengths among the temporal/cultural zones.

b. Input the temporal/cultural zone data into the four model stages.

c. If Pacific cod fork lengths are significantly smaller during specific model stages and those differences cannot be attributed to climate zones, the null hypotheses may be rejected.

Research Question 8: Is there evidence of resource intensification, as indicated by an increase in salmon abundance (Salmon Index), a decrease in evenness (Shannon Index of Evenness), and evidence of storage (as determined by skeletal element representation), among the Mink Island temporal/cultural zones?

Null Hypothesis 8a: There is no evidence of increasing salmon abundance (Salmon Index) among the temporal/cultural zones at Mink Island. H_0: $p \geq .05$

Null Hypothesis 8b: There is no evidence of decreasing evenness (Shannon Index of Evenness) among the temporal/cultural zones at Mink Island. H_0: $p \geq .05$

Null Hypothesis 8c: There is no evidence of storage (as determined by skeletal element representation) among the temporal/cultural zones at Mink Island. H_0: $p \geq .05$

Alternate Hypothesis 8a: There is evidence of increasing salmon abundance (Salmon Index) among the temporal/cultural zones at Mink Island. H_a: $p<.05$

Alternate Hypothesis 8b: There is evidence of decreasing evenness (Shannon Index of Evenness) among the temporal/cultural zones at Mink Island. H_a: $p<.05$

Alternate Hypothesis 8c: There is evidence of storage (as determined by skeletal element representation) among the temporal/cultural zones at Mink Island. H_a: $p<.05$

Zooarchaeological Methods 8:

a. Sort fish remains by skeletal element, taxon, temporal/cultural zone, and model stage.

b. Create a salmon index using the following formula: ∑NISP salmon/ (∑NISP salmon + ∑NISP other taxa).

c. Use the salmon index results to infer Patch Choice: ∑NISP salmon (riverine patch)/ [∑NISP salmon (riverine patch) + ∑NISP other taxa (nearshore marine patch)].

d. Measure taxonomic richness (NTAXA) for the temporal cultural zones.

e. Measure Shannon-Wiener heterogeneity index using the following formula ($H= -\sum P_i(\ln P_i)$.

f. Measure evenness using the Shannon Index of Evenness ($e=H/\ln S$).

g. Measure salmon storage by aggregating salmon remains by temporal/cultural zone and by body region (e.g. cranial, pectoral, pelvic, vertebral, and tail regions). Compile MNE, MAU, and %MAU values. Higher abundance associated with pectoral, pelvic, vertebral and tail regions indicate salmon storage (Butler and Chatters, 1994; Partlow, 2000).

h. Compare intensification data from temporal/cultural zones to the four model stages.

Statistical Methods 8:

a. Use one-way ANOVA statistical analysis to determine if there are significant differences in Salmon Index values among the Mink Island temporal/cultural zones.

b. Use one-way ANOVA statistical analysis to determine if there are significant differences in Shannon Index of Evenness values among the Mink Island temporal/cultural zones.

c. Use one-way ANOVA statistical analysis to determine if there are significant differences in skeletal element representation values among the Mink Island temporal/cultural zones.

Laboratory Methods

During the first stage of zooarchaeological analysis, the Mink Island fish remains were separated from other faunal remains and grouped into vertebrae and non-vertebrae categories. A laboratory tag, that included the accession number, catalog number, N/E coordinates, and stratigraphic level was added to each bone bag. The same information was entered into an Excel spreadsheet. Fish remains were organized by locus (Upper Midden Excavation Area A, Column Sample, House Feature 5, and Lower Midden), N/E coordinates, and stratigraphic level.

During the second stage of analysis, the fish remains were separated into identifiable and too fragmentary to identify beyond class (e.g. osteoichthyes) categories. Non-vertebrae were identified by skeletal element (e.g. dentary, premaxilla, etc.), individually bagged, tagged, and recorded in the spreadsheet. Vertebrae were identified by type (thoracic, precaudal, caudal, etc.), group bagged, tagged, and recorded in the spreadsheet. Identifications were made using modern synoptic comparative collections belonging to the UAF Department of Anthropology, the Alaska Consortium of Zooarchaeologists, and myself. Taxon-specific information was added to the laboratory tags and recorded in the spreadsheet. The side (right or left), completeness %, burned (y or n), and catalog number, was also recorded.

Fish Bone Analysis

The methods used by zooarchaeologists to recover (sieving strategies) and analyze (general and fish-specific methods) archaeological fish bones are presented in this section. Sieving strategies, which range in size from 0.64 cm (1/4 in) to 0.16 cm (1/16 in), are presented. Descriptions of the general abundance measures (NISP, MNE, MNI, MAU, and rank order) that were developed to quantify assemblages comprised mostly of mammals and birds, but were adjusted here to accommodate fishes are also included. Descriptions of fish-specific methods (extrapolating length and weight from specific fish bones, ascertaining season of death from fish bones, and ascertaining age-at-death from fish bones) conclude this section.

Sieving Strategies

Fish remains tend to be small and friable, and therefore, are often overlooked while excavating archaeological contexts (Casteel, 1972). Therefore, when fish remains are present, sieving strategies must be adjusted. Evenness (the distribution of abundance values) and richness (the number of taxa present) values differ depending on the mesh size used (Bobrowsky and Ball, 1989; Casteel, 1972; Gordon, 1993; Grayson, 1984; Lyman, 1994; Partlow, 2006; Payne, 1972a; Vale and Gargett, 2002; Wheeler and Jones, 1989). Therefore, differing mesh sizes result in differing fish bone assemblages.

The best mesh sizes to use will vary depending on the research question(s) (Clason and Prummel, 1977). The potential advantages and disadvantages of using a particular mesh size must be weighed to optimize data collection and minimize time and expense. The use of small mesh sizes (0.32 cm, 0.16 cm) (1/8 in, 1/16 in) may result in greater NISP, MNI, and evenness values (Gordon, 1993; Lyman, 1994, 2008). Therefore, smaller mesh sieve sizes are better for collecting fish bones from archaeological contexts (Barker, 1975; Casteel, 1972; Clason and Prummel, 1977; Jones, 1982; Levitan, 1982; Payne, 1972b; Spencer, 1979; Wheeler and Jones, 1989).

Disadvantages of using small mesh sieve sizes are that archaeological sediments must pass through smaller holes, which increases sieving time and effort. The lab time needed to

process greater numbers of bones also increases and recovered bone is smaller and more fragmentary, and may provide little return other than increased NiSP values (Butler, 1988; Casteel, 1972; Gordon, 1993; Ross and Duffy, 2000; Vale and Gargett, 2002; Wheeler and Jones, 1989).

An alternative sieving strategy where most of the archaeological sediment is passed through 0.32 cm (1/8 in) mesh, and a sample is passed through 0.16 cm (1/16 in) mesh may be preferred. This method allows the researcher to determine which taxa and skeletal elements are present at an archaeological site without encumbering the project with numerous bones too fragmentary to identify. If time and money constraints restrict the use of 0.32 cm (1/8 in) mesh over the entire site, another option would be to collect a bulk soil sample and pass the sediments though stacked sieves (0.64 cm, 0.32 cm, 0.16 cm; 1/4 in, 1/8 in, 1/16 in) to determine which bones/taxa are being lost (Partlow, 2006).

Analytical Methods

Fish bone specialists typically use a combination of general zooarchaeological abundance measures and fish-specific methods to analyze fish bone data (Casteel, 1976a; Monks, 1981; Reitz and Wing, 1999). General zooarchaeological abundance measures NISP, MNI, MNE, and MAU were developed to quantify faunal assemblages comprised mostly of mammals and birds. Fish bone specialists have achieved limited success adapting these measures to quantify fish bone assemblages (Reitz and Wing, 1999). Those general abundance measures best suited for fish remains are emphasized in the following sections. Because fish bone specialists regularly use fish-specific analytical methods (e.g. extrapolating length and weight from specific fish bones, and ascertaining season and age of death from specific fish bones); they are described in detail in the following subsections.

Number of Identified Specimens (NISP)

NISP consists of a count of the total number of identifiable fragments per taxon (species, genus, family, or higher taxonomic category) in a given faunal sample (Grayson, 1984; Lyman,

1994, 2008). NISP measures abundance within the recovered faunal assemblage (Grayson, 1984; Lyman, 1982, 2008). Inferences about temporal and spatial changes in deposited archaeological assemblages may be made using NISP (Grayson, 1984; Lyman, 1982, 2008). NISP may be transformed into MNI or MNE counts, be used to estimate the size of the death population, or be used to estimate animal weights (Grayson, 1984).

While NISP is simple to calculate, it is plagued by several biases that affect values (Klein and Cruz-Uribe, 1984). The NISP technique does not account for differential bone preservation (Bunn *et al.,* 1988; Gilbert and Singer, 1982; Grayson, 1984; Holtzman, 1979; Kent, 1993), nor does it account for differential identifiability of specific taxa and skeletal elements (Grayson, 1984; Reitz and Wing, 1999). Additionally, there is a lack of agreement as to what constitutes a countable specimen (Casteel, 1972; Grayson, 1984; Lyman, 1994, 2008). Therefore, differing methods result in different NISP counts, which often prevent the direct comparison of multiple assemblages (Klein and Cruz-Uribe, 1984).

Fish remains tend to be small and fragile; as a result, taphonomic agents (see Chapter 5) tend to affect fish bones at a faster rate than they affect bird or mammal bones. Because of these differences, individual fish specimens may be more fragmentary than are their bird or mammal counterparts. Therefore, fish may have higher NISP values than mammals or birds despite being represented by the same number of individuals. This problem of differential fragmentation may be overcome by comparing %MNE, %MNI, and %MAU values with %NISP values. Significant differences in values between the abundance measures may indicate differential fragmentation (Lyman, 1994).

When compiling NISP values for the Mink Island fish bone assemblage, only those fish bones that were identified to family-level taxonomic grouping and skeletal element were counted. If a skeletal element was too fragmentary to identify beyond class, it was not included in NISP counts. Because of the excavation strategy employed at the Mink Island site (see Chapter 4), fish bone NISP values were vastly different among the assemblages (e.g. Upper Midden Column Sample, Lower Midden, etc.). To overcome sample size problems, %NISP values are used to compare abundances.

Minimum Number of Elements (MNE)

MNE is the "minimum number of complete skeletal elements necessary to account for all observed specimens" (Lyman, 1994: 290). MNE is essentially a modification of NISP values that estimates the number of skeletal elements represented in fragmented bone assemblages (Marean *et al.*, 2001; Lyman, 2008). MNE estimates are the foundation for MNI and MAU calculations (Marean *et al.*, 2001). MNE aids researchers in determining why some of the skeletal elements that make up a complete animal skeleton are not recovered from archaeological contexts (Lyman 1994, 2008).

There are a number of ways to calculate MNE values, which include estimates based on whole elements, shaft fragments, articular ends, and diagnostic zones (Bartram, 1993; Bunn, 1986; Bunn and Kroll, 1986; Klein and Cruz-Uribe, 1984; Lyman, 1994; Marean *et al.*, 2001; Watson, 1979). Each method varies in its degree of accuracy and applicability, especially when dealing with fish bones. Watson's (1979) method, which uses small diagnostic zones (e.g. areas on bones that possess species-specific morphology, are free of age bias, and are rarely broken), was used for this research. Watson's small diagnostic zone method is better suited for use with fish bones because these areas are often the only portion of the skeletal element that is preserved.

Minimum Number of Individuals (MNI)

MNI is a measure of the smallest number of individuals necessary to account for all of the specimens (skeletal elements) of a particular taxon in a given archaeological assemblage (Shotwell, 1955, 1958). MNI has been calculated several different ways since the 1950's, when it was first used by American Archaeologists (Grayson, 1973; Lyman, 2008). White's (1953) method, which uses the most abundant sided (right or left) skeletal element from a particular taxon, was used for this dissertation research.

Problems associated with calculating MNI values are numerous, and may prohibit the effective use of this abundance measure (Payne, 1972b). When sample size is inadequate, rare taxa may be over-estimated (Payne, 1972b). Additionally, different aggregation units for the

same archaeological assemblage will provide different MNI values (Grayson, 1978). MNI, therefore, simply reflects the differing sample sizes from which values have been derived (Grayson, 1982).

MNI calculations of fish bone assemblages have been variably successful (Reitz and Wing, 1999). Wheeler and Jones (1989) suggest that the bones from the mid-line of the neurocranium that are represented by a single element are the best bones for calculating MNI values. The vomer, basioccipital, supraoccipital, and the parasphenoid all fit this description; however, only the vomer and the basioccipital are readily identifiable and are dense enough to survive as recognizable bones (Wheeler and Jones, 1989: 149). Paired skeletal elements are potentially as useful, because they can be easily sided as left or right (Krantz, 1968; Nichol and Wild, 1983; Orchard, 2003; Wheeler and Jones, 1989). Of these paired fish elements, the premaxilla, maxilla, and dentary are most useful. These paired elements are highly identifiable, and typically survive well in archaeological contexts (Wheeler and Jones, 1989). Because paired elements (e.g. dentaries) were the most abundant within the Mink Island fish bone assemblage, they were used to derive MNI values for this dissertation research.

Minimum Animal Units (MAU)

MAU is a count of the minimum number of animal units necessary to account for all of the observed specimens (Binford, 1978, 1984; Binford and Bertram, 1977). MAU is calculated by determining the minimum number of particular skeletal parts (e.g. proximal articular or distal quadrate) in a faunal collection (MNE), and dividing by the number of times the element is present in a complete skeleton of the animal (Binford, 1978, 1984). After deriving the MAU for each skeletal element, the largest MAU value is used as the standard for the entire assemblage (Binford, 1978). Binford (1978, 1984) developed MAU because he did not believe that the entire animal (as expressed in MNI counts) was the most appropriate unit of analysis. Binford noted that meat was utilized in segments (e.g. cranial or post-cranial portions for fish); MNI values obscure the existence of these segments (Binford, 1978).

MAU calculations may be problematic; bone fragmentation often obscures the number of animal units present in the assemblage (Grayson, 1984). Fragmentation may be overcome by

using MNE values as the basis for MAU calculations. Therefore, MAU calculations are subjected to the same aggregation problems associated with MNE counts (Grayson, 1984).

MAU estimates derived from fish bone assemblages may identify butchery practices and can aid in deciphering subsistence strategies (e.g. storage) (Partlow, 2000, 2006). If a fishbone assemblage is primarily composed of post-cranial elements, it may indicate a village context. Conversely, if the fishbone assemblage is primarily comprised of cranial elements, it may indicate a fish-processing context (e.g. salmon stream) (Hoffman *et al.,* 2000; Partlow, 2000, 2006).

Rank Order

Because NISP, MNE, MNI, and MAU estimates bear an unknown relationship to the actual abundances of individual taxa, animal units, or skeletal elements recovered from archaeological contexts, they are ordinal-scale measures (ranked) (Grayson, 1984; Lyman, 2008). With an ordinal-scale, those taxa, animal units, or skeletal elements with the largest number are ranked #1, and those with the next largest are ranked #2, and so on. NISP estimates represent the maximum number of individual taxa, animal units, or skeletal elements whereas MNI, MAU, MNE estimates represent the minimum number of individual taxa, animal units, or skeletal elements, respectively, that are recovered from an archaeological site (Grayson, 1984). In reality, actual individual taxa, animal units, or skeletal elements are most often somewhere between those measures.

NISP, MNI, MAU, and MNE estimates may provide acceptable estimates of the Rank Order of some common taxa, but may be affected by calculation problems. Differing aggregation strategies may result in differing Rank Orders even when analyzing a single faunal assemblage. The stability of Rank Order between the different measures is closely linked with sample size and the degree of separation of the number of individual taxa, animal units, or skeletal elements (Cannon, 1995; Grayson, 1984). Differences in Rank-Order are largely because of differing aggregation strategies and inter-observer identification ability differences (Grayson, 1984; Lyman, 2008).

Some differences in Rank Order may be overcome by completing taphonomic analysis before completing zooarchaeological analyses (Cannon, 1995; Gifford *et al.*, 1980; Grayson, 1984). If the Rank Orders from NISP, MNI, MAU, and MNE measures are the same, it is clear that all of the measures are providing an accurate assessment of the Rank Order. If there are differences in Rank Order between the different measures, those taxa whose Rank Order is the most divergent from NISP as compared to MNI, MAU, and MNE should be used as the measuring unit (Grayson, 1984).

Rank Order is a good measure to use, especially when dealing with fishbone assemblages. Rank Order is easy to calculate, and it helps identify differential preservation due to biostratinomic and diagenic agents. The Rank Order strategy is employed in this dissertation in Chapter 7 when it is used to determine which Pacific cod skeletal element is best suited for stable isotope analysis.

Fish Length from Specific Skeletal Elements

Researchers have used five distinct methods for extrapolating live fish length of individuals from archaeological fish bones. Methods vary in simplicity, accuracy, and data requirements; and are from least suitable to most suitable: Cook and Treganza's (1950), White's (1953), proportional, double regression, and single regression (Casteel, 1976a). Because the single regression method is the most suitable method, it is covered in detail here.

The regression (allometric) approach extrapolates the size of a whole animal from the dimensions of a part (Reitz and Wing, 1999: 70). Regression compares animal length to measurements of certain skeletal elements (Orchard, 2003). The regression approach as has been used by many researchers on fish remains (Casteel, 1974a, 1974b, 1976a; Crockford, 1997; Desse and Desse-Berset, 1996a, 1996b; Enghoff, 1983; Hales and Reitz, 1992; Leach and Davidson, 2000; Noe-Nygaard, 1983; Orchard, 2003; Rojo, 1986, 1987). Paramount to the application of this method is the assumption that the size of a live fish is highly correlated with the size of their individual skeletal elements (Casteel, 1976a; Orchard, 2003). The least-squares regression method is the most often used for extrapolating the relationship between these individual bone measurements and the length of the animal (Casteel, 1976a; Orchard, 2003;

Ricker, 1973). This method plots the two variables under consideration (X and Y) against each other. It creates the equation for the line that minimizes the sum of squares of the distance between the regression-line to the data points (Casteel, 1976a; Orchard, 2003; Ricker, 1973). The following linear regression formula may be used to determine overall length.

$$y=\alpha+\beta x$$

Where y represents the live length of a fish, x represents the skeletal element that is being compared, and α and β are the constants that define the regression formula (Orchard, 2003).

Season of Death (Site Occupation Seasonality)

Seasonality is defined as "the time of the year at or during which a particular event is most likely to occur" (Monks, 1981:178). Time of the year may be expressed in sequential dates (i.e. spring) or calendric dates (i.e. May 15). Season of death may be ascertained from fish remains using the presence/absence of seasonally available taxa, incremental structures, and population structure methods (Monks, 1981). Methods vary in respect to simplicity, accuracy, and data requirements; and, therefore, in applicability.

The presence of seasonally available taxa is the easiest, oldest, and most extensively used method (Leach, 1979; Monks, 1981; Nichol, 1982a; Reitz and Wing, 1999). The incremental structures method, that measures and counts incremental growth structures found within specific skeletal elements, is also regularly used (Casteel, 1974b; 1976a; Higham and Horn, 2000; Monks, 1981; Reitz and Wing, 1999; Smith, 1983; Wheeler and Jones, 1989). While the incremental structures method works well for otoliths, scales, opercles, and vertebrae, it is not suitable with more common skeletal elements that typically comprise fish bone assemblages. Other problems associated with preservation, time consumption, cost, and reader error (Reitz and Wing, 1999; Wheeler and Jones, 1989), make the incremental structures method impractical here. The population structure method uses age estimates derived from incremental structures, and therefore is plagued by the same problems associated with preservation, time consumption, cost, and reader error (Reitz and wing, 1999).

Using the presence of seasonally available taxa method, site occupational seasonality may be determined by recording the presence of seasonally available fish species (i.e. salmon or

herring) within a particular zooarchaeological assemblage. Prehistoric peoples are then inferred to have inhabited an area during the time of year that the seasonally available resources were present (Leach, 1979; Monks, 1981; Nichol, 1982a; Reitz and Wing, 1999). Essential to the calculation of this method is the assumption those modern biological and climatic cycles are similar to those in the past (Reitz and Wing, 1999), and differential access to seasonally available resources by modern anglers is consistent with that of prehistoric peoples (Leach, 1979: 112). Accurate calculation requires the consultation of ethnographic and ecological records for the region in question (Monks, 1981). The ethnographic consultation is necessary since some fish resources may be available year-round but are only collected during limited times when they are considered to be in prime condition (Leach, 1979; Monks, 1981). Other fish species may be present year-round but are difficult to obtain during certain periods because of altered patterns associated with water temperature changes (Leach, 1979).

While the presence of key seasonally available resources is a good site occupation seasonality indicator, several problems affect this method. Storage or transport of seasonally available remains may bias estimates (Monks, 1981; Reitz and Wing, 1999). Transportation may remove some of the seasonality indicators from an acquisition area (e.g. fishing station) and deposit it in another location (e.g. village) (Monks, 1981; Partlow, 2000, 2006). The presence/absence of key seasonally available resources (e.g. salmon) method was used for this dissertation research to estimate site occupation seasonality at the Mink Island site.

Age at Death

Population structure, incremental structures, and single linear regression are the three methods used to estimate age at death from fish bones (Monks, 1981; Orchard, 2003). The age at death estimates derived using the incremental structures method (otoliths, scales, opercles, and vertebrae) are subjected to the same biases (skeletal element preservation, time consumption, cost, and reader error) that plague season of death estimates. Therefore, incremental structures are not used here. Because the population structures method also relies on age estimates derived from incremental structures, this method is also omitted. The single

regression method, which was previously described in the fish length from specific skeletal elements section, is used here.

The single linear regression method may be used to establish the length of fish taxa as discussed earlier (Orchard, 2003; Rojo, 1986, 1987), which can then be used as a proxy for age (Foucher and Fournier, 1982; Orchard, 2003; Rojo, 1986, 1987). Fish species grow at known rates, therefore, by reconstructing the fork length of the fish from the dimensions of a single skeletal element (vomer, dentary, angular, premaxilla, quadrate, epihyal, interhyal, hypobranchial #3, pharyngobranchial #2, and the atlas vertebra), the age of the fish may be estimated (Orchard, 2003; Rojo, 1986, 1987; Schnute and Fournier, 1980).

Changes in the age structure of fishes recovered from archaeological contexts may reflect changes in predation, food availability, climatic conditions, disease levels, or space (overcrowding) (Klein and Cruz-Uribe, 1984; Reitz and Wing, 1999). It is important to be able to link changes in environmental conditions with changes in fish bone sizes to determine if the cause of fluctuating body size is a result of human exploitation pressure or other environmental factors (Reitz and Wing, 1999). Changes in body dimensions may also provide data on the differing nutritional contributions made by each fish species to the human diet (Reitz and Wing, 1999). Any shifts over time suggest a change in foraging strategies, and thus indicate the presence of resource depression (Kopperl, 2003; Reitz and Wing, 1999).

Chapter 3. Environmental Setting

Introduction

The regional environmental context (physiography, climate, tectonism, sea levels, geology, volcanism, and glaciation) and the local resource distributions (flora and fauna) are presented in this chapter. Because volcanism, tectonism, sea level fluctuations, and climatic variations have caused biological resource distributions (flora and fauna) to vary over time (Jordan and Krumhardt, 2003), human subsistence and habitation strategies have also varied. Therefore, the background contextual data (especially paleoenvironmental reconstructions) is essential to our understanding of human prehistory at the Mink Island site. The environmental context information is presented by sub-region where appropriate; however, in instances where environments from the sub-regions overlap, their descriptions have been combined. The regional archaeological and cultural history of the Shelikof Strait coast, the Kodiak Archipelago, and the Bering Sea slope is presented in the following chapter.

Regional Environmental Context

Physiography

The Alaska Peninsula is in southwestern Alaska and extends from Lake Iliamna in the east to Unimak Island to the west (Figure 3.1). The Peninsula is 475 miles long and averages 50 miles across. The peninsula is bounded on the northwest by Bristol Bay and the Bering Sea and on the southeast by Shelikof Strait (Hussey, 1971; Partnow, 2001). The Aleutian Range dominates the length of the Alaska Peninsula's southeast shore. The crest of the Aleutian Range forms the drainage divide between the Shelikof Strait and the Bering Sea slopes (Hussey, 1971).

The Aleutian Range is volcanic in origin and has six mountains with peaks higher than 7000 feet (giants) including Mount Douglas, Mount Steller, Mount Denison, Mount Griggs, Snowy Mountain, and Mount Mageik (Hussey, 1971; Keller and Reiser, 1959). Before Mount Katmai erupted in 1912, it had an elevation of 7500 feet; however, its eruption lowered the

peak to its current elevation of 6715 feet (Hussey, 1971). There are many high mountain dispersed between the giants as well as fifteen active or recently active volcanoes (Cahalane, 1959; VanderHoek, 2009).

The Shelikof Strait coast follows along the eastern slope of the Aleutian Range and extends from Wide Bay in the south to Kamishak Bay in the north. Driftwood-covered beaches, deep fjords, rugged cliffs, craggy islands, and gentle lagoons variously characterize this coastline (Crowell *et al.*, 2003; Hussey, 1971). The southern and northern portions of the coast are dominated by sandy, wide, crescent-shaped bays (Kashivik, Katmai, and Dakavak in the south; Hallo, Kaguyak, and Swikshak in the north). The northern coast also contains many broad beaches, is dotted with ponds, and swamps (Crowell *et al.*, 2003). A submerged, rocky coastline with deep fjord-like bays (Amalik, Missak, Kuliak, Kaflia, and Kukak Bays) dominates the middle portion (Cahalane, 1959; Crowell *et al.*, 2003; Hussey, 1971; USGS, 1958).

The Bering Sea slope is on the eastern side of the Aleutian Range and has a more gradual grade compared to the Shelikof Strait coast (Figure 3.1) (Cahalane, 1959). Stream flow on this slope tends to be slower and streams are often braided (Hussey, 1971). The Naknek River and its tributaries (Savonoski River, Ukak River, Hardscrabble Creek, and Ikagluik Creek) drain most of the slope. These creeks and rivers tend to be clouded with sediments because they are glacially fed (Hussey, 1971). Several lakes in the region (Brooks, Naknek, Idavain, Coville, and Grosvenor Lakes) are deep, cool, clear, and blue because they are not affected by glacial run-off (Hussey, 1971). At an elevation of 500 feet between the Bristol Bay coast and Kukaklek, Nonivianuk, and Naknek Lakes, lies poorly drained glacial outwash lowland (Wahrhaftig, 1965). The Bristol Bay coast is low and featureless except for bays at the mouths of the Ugashik, Egegik, Naknek, and the Kvichak rivers. Sea ice may be found along the coastline during the winter months (Crockford and Frederick, 2007; Dumond, 1987b, 1998, 2005).

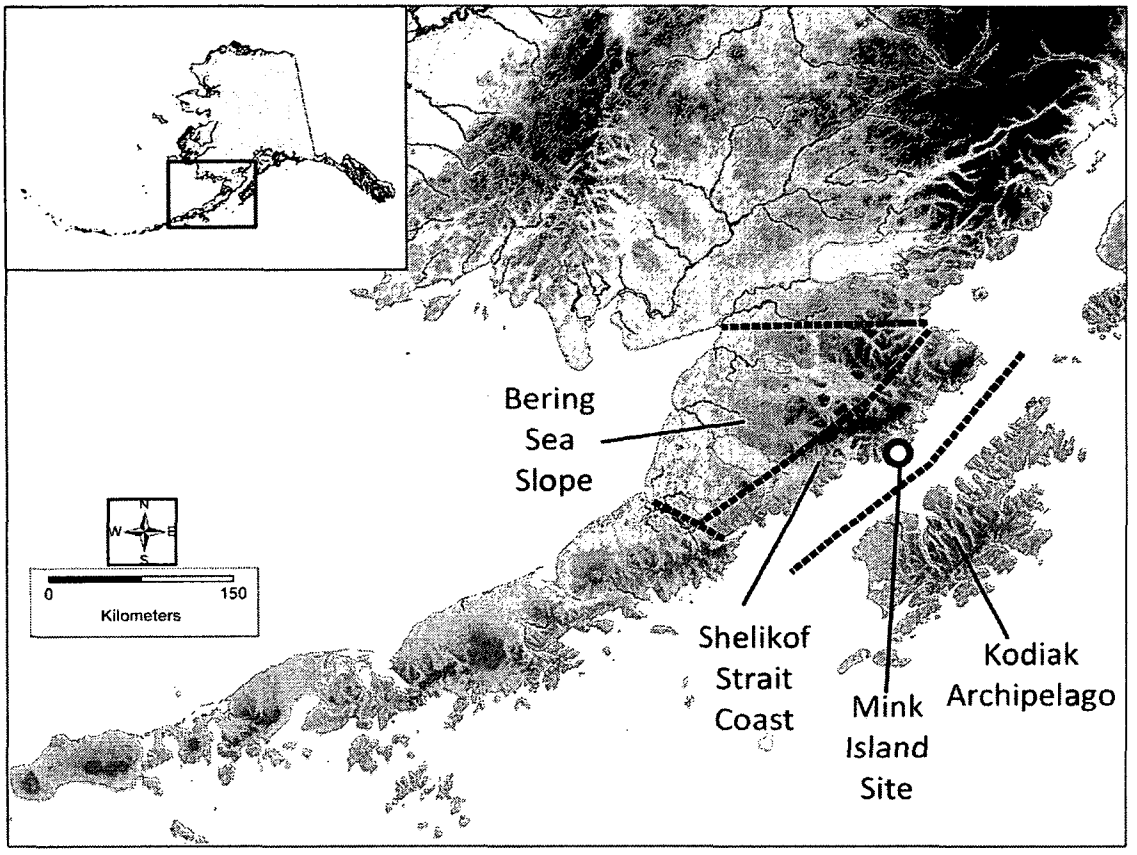


Figure 3.1. Location of study area, sub regions, and the Mink Island site (XMK-030).

The Kodiak Archipelago is southeast of the Alaska Peninsula, and is bounded on the southeast by the North Pacific Ocean and on the northwest by Shelikof Strait (Figure 3.1) (Wahrhaftig, 1965: Plate 1). The archipelago is comprised of thirteen islands and numerous islets that span the distance from Shuyak Island in the northeast to Tugidak Island in the southwest. The archipelago is 177 miles long and 67 miles wide, covering 5000 square miles, including ca.1000 miles of coastline (Clark, 1975; Karlstrom, 1969). The rivers within the archipelago tend to be small except Ayakulik and Karluk Rivers in the southwestern portion of Kodiak Island (Heizer, 1956). The archipelago contains numerous small lakes and ponds (Heizer, 1956).

Modern Climate

The Shelikof Strait coast and the Kodiak Archipelago share a maritime climate, affected by the westerly-flowing coastal extension of the Alaska Current and the easterly-flowing Alaskan Stream derived from the warm Japanese Current (Reed and Schumacher, 1986; Weingartner, 2005). The effects of these ocean currents allow bays and fjords to remain ice-free throughout the winters (Dumond, 1987a, 1998; Wilson and Overland, 1986). The prevailing weather patterns produce low-pressure cyclones that track along the Aleutian Islands from the west and hit the region with force. During the winter months, strong storms can generate surface winds in excess of 56 miles/hour at an average of once every four or five days (Wilson and Overland, 1986). Precipitation is not evenly distributed within the region; averages range between 62 (bordering the Gulf of Alaska) and 23 (bordering Shelikof Strait) inches of annual precipitation (The Climate Zone, accessed 4/26/2011). During the summer months, the region experiences fewer low-pressure storms, which results in weaker winds and increased overall visibility (Wilson and Overland, 1986). Average temperatures at Kodiak, Alaska, range from 34.8 to 46.8 degrees Fahrenheit (The Climate Zone, accessed 4/26/2011).

The Bering Sea slope is at the junction between the maritime climate zone of the North Pacific Ocean and the transitional zone of the continental climate of the interior. The Aleutian Range is the dividing line between climate zones (Dumond, 1987a). As weather systems originating in the North Pacific Ocean pass over the Aleutian Range, most of the precipitation falls on the eastern slope, leaving the western slope relatively dry (rain shadow effect). The climate of the Bering Sea slope has more pronounced temperature variations, fewer clouds, and less precipitation compared to the maritime climate zone (Pewe, 1975). Annual precipitation on the Bering Sea slope averages 20 inches, which is less than the 62 inches that falls on parts of the maritime climate zone (Wilson and Overland, 1986). Average temperatures at King Salmon range from 26.1 to 42.2 degrees Fahrenheit (WRCC, n.d., accessed November 30,2005).

Tectonism and Sea Level Change

The Alaska Peninsula sits at the edge of the North American continent on the North American plate. The adjacent North Pacific Ocean rests on the Pacific plate, which is subducting in a northwestward direction beneath the North American Plate at a rate of 2 to 2.8 inches per year (Hood, 1986; Pflacker and Berg, 1994a; Riehle, 2002). Key features of the regional tectonic environment include the Aleutian trench, the continental shelf, and the Aleutian arc of active volcanoes that extend from the Alaska Peninsula to the Aleutian Islands (Riehle, 2002). The subduction of the Pacific plate creates earthquakes, tsunamis, volcanoes, and affects sea levels (Crowell and Mann, 1996; Riehle, 2002).

Earthquakes occur because of friction between the two tectonic plates. As the Pacific Plate subducts below the North American Plate, it sometimes becomes locked in place until the friction is overcome and the stress is released instantaneously as an earthquake (Riehle, 2002). The resulting shaking, subsidence, avalanches, landslides, seiches, and soil liquefaction causes local devastation (Hood, 1986). More far-reaching devastation may also occur in the form of tsunamis, which may travel for thousands of miles across large bodies of water (Hood, 1986; Riehle, 2002).

Sea level changes have been occurring along the Shelikof Strait coast and Kodiak Archipelago because of tectonic, isostatic, and eustatic processes (Crowell and Mann, 1996; Fitzhugh, 1996; Johnson and Winslow, 1991; Jordan, 2000; Maschner, 1999). The effects of tectonic sea level changes occur in two stages. The descending portion of the Pacific Plate drags down the overlying North American Plate, causing a gradual rise in sea level during the first stage. The instantaneous release (earthquake) of the accumulated stress between the two plates causes the North American Plate to uplift, and the Pacific Plate to subside, thus raising and lowering sea levels during the second stage (Crowell and Mann, 1996).

The relationship between tectonic processes and sea level changes is better understood because of the research relating to the 9.2-magnitude earthquake that hit Prince William Sound, Alaska on March 27, 1964 (Jacob, 1986). The earthquake caused crust deformation (uplift, subsidence, and horizontal movements) for as many as 100,000 square miles (Pflacker, 1969). Subsidence occurred along the Kodiak Archipelago, Cook Inlet, the Kenai Peninsula, and

northeastern portion of the Shelikof Strait from Amalik Bay to the southern shore of Kamishak Bay. Uplift occurred on the Gulf of Alaska seafloor to the southeast of the Kodiak Archipelago and the Kenai Peninsula (Pflacker, 1969).

The effects of isostatic rebound must also be considered when examining sea level changes. Sea levels rose during the early and mid-Holocene when temperatures increased and Pleistocene glaciers melted and withdrew from the region (Crowell and Mann, 1996; Jordan and Maschner, 2000). As the immense weight of the glacier was removed from the landform, it slowly began to rise until it reached its pre-glaciated level (Hamilton *et al.*, 1986). Isostatic rebound was completed in the region by 7000 to 8000 BP (Gilpin, 1995).

Eustatic sea level changes also affected coastal areas of the region. Large-scale melting of glaciers during the Holocene produced a freshwater influx that caused sea levels to rise on a global scale (Gilpin, 1995). There was an increase in sea level during the mid-Holocene between 7000 and 1300 BP (Gilpin, 1995: 191).

The effects of tectonic activity and isostatic rebound on sea levels may be highly localized; and are major players in the formation and destruction of the archaeological record in coastal areas (Crowell *et al.*, 2003; Saltonstall and Carver, 2002). Because human settlements were often along the coast, an abrupt rise in sea level may have forced occupants to abandon their homes (Clark, 1994; Crowell, 1994b).

Changes in sea level also affected the coastal ecology of the region by altering the tidal regimes of marshes and lagoons. Marshes and lagoons are typically biologically productive water bodies and any alterations may affect resource abundances, which may favor certain taxa over others (Gilpin, 1995). The abrupt raising or lowering disrupts shellfish beds, often beyond their ecological tolerances. As shellfish constituted a major portion of the local diet during certain periods, their habitat destruction may have negatively affected human habitation (Fitzhugh, 1996).

Within the Kodiak Archipelago, the southeast coastline is uplifting at a rate of 0.03 to 0.07 inches annually, whereas the northwest varies between co-seismic submergence and post-seismic uplift (Fitzhugh, 1996). Along the Shelikof Strait coast, sea level fluctuated over the millennia. At around 10,000 BP, sea level was 4.10 feet lower than currently. The sea level rose above the current level around 7000 BP and became 3.28-6.56 feet higher than the current level

by 4000 BP. At around 3000 BP, the sea level dropped lower than the current level (Crowell and Mann, 1996; Hilton, 1998; Schaaf, 2009). Several sites in Amalik Bay (including the Mink Island site) are currently submerging because of a 1.64-feet rise in sea level over the past 300 years (Crowell and Mann, 1996; Hilton, 1998). The Bering Sea slope sea level history has not been as extensively studied as the sea level history of the other sub-regions (e.g. Crowell and Mann, 1996; Fitzhugh, 1996; Hilton, 1998). Although there is evidence for sea level fluctuations (drowned river mouths and beach ridges), the effects of tectonic activity and isostatic rebound were relatively minor compared to the other sub-regions (Dumond, 1987a). The Shelikof Strait coast and the Kodiak Archipelago are at the juncture (dynamic zone) of the Pacific and North American Plates whereas the Bering Sea slope is outside the dynamic zone on the North American Plate. Therefore, tectonically induced changes in sea level typically did not affect the coastline of the Bering Sea slope (Dumond, 1987a).

The Bering Sea Slope was also less affected by isostatic rebound as compared to the Shelikof Strait coast because that region was less heavily glaciated (Dumond, 1987a). As stated in the climate section, winter storms deposit the bulk of their precipitation (snow in the higher elevations) on the eastern slope of the Aleutian Range (Wilson and Overland, 1986). The western slope (Bering Sea side) of the range receives much lower amounts of snow, therefore, the glaciers tended to be smaller, and associated isostatic rebound was reduced (Dumond, 1987a). There is evidence for eustatic sea level rise on the Bering Sea slope coast. At Kvichak Bay, on the lower Alaska Peninsula, eustatic sea level rise resulted in a drowned river mouth (Dumond, 1987a). Further research is needed to understand the effect that sea level change had on the development and destruction of archaeological sites on the Bering Sea slope.

Geology

The Upper Alaska Peninsula, including the Bering Sea slope and the Shelikof Strait coast, is divided into three northeast to southeast trending geological zones (Riehle *et al.*, 1993). The geological zone along the Bering Sea coastline is composed of unconsolidated to poorly consolidated glacial, marine, lacustrine, colluvial, alluvial, and eolian deposits (Riehle *et al.*, 1993). The geological zone along the Shelikof Strait coastline between Cape Nukshak to Cape

Ilktugitak is comprised of Late Tertiary-aged basaltic, dacitic, and andesitic lava flows. These lava flows formed the islands in Amalik Bay (Takli, Little Takli, and Mink) (Riehle *et al.*, 1993). Lying underneath the lava flows is a poorly hardened conglomerate of sandstone, siltstone, coal, shale, and tuff known as the Hemlock Conglomerate (Riehle *et al.,* 1993).

The Kodiak Archipelago is part of a northeast to southeast trending mountainous ridge system that is an extension of the Kenai and Chugach mountains of the Kenai Peninsula and Prince William Sound (Heizer, 1956). The ridge was formed by the folding and uplift associated with the subduction of the Pacific plate below the North American plate (Jacob, 1986). The faulting, folding, and tilting associated with subduction created three distinct geological zones ranging in age from Mesozoic to Tertiary (Karlstrom, 1969). A more complete description of the regional geology may be found in Tennessen (2009).

Volcanism

Subduction of the Pacific Plate beneath the North American Plate has produced a line of active volcanoes that spans the Gulf of Alaska coast from Sitka to the eastern Aleutian Islands (Miller and Smith, 1987; Riehle, 2002). During the Late Quaternary, twelve caldera-forming eruptions occurred in the eastern Aleutian arc; the Mount Katmai (Novarupta) eruption in 1912 is the most recent (Riehle, 2002). Because these volcanoes contained magma that was silicic and viscous, they erupted violently and produced ash and pyroclastic flows, which affected the landscape (VanderHoek and Myron, 2004).

When ash falls on a landscape, it seriously affects the environment. Ash deposits are initially harmful because they clog the air, blanket the ground, disrupt vegetation, pollute drinking water, and cause residual silting of bogs, ponds, salt marshes, and oceans (disrupting fish and shellfish habitat) (Griggs, 1918). Long-term effects are less harmful; in fact, volcanic eruptions may be ecologically productive (Dumond, 1979; Eicher and Rounsefell, 1957). Volcanic ash contains many free minerals, which fertilize the soil and eventually end up in rivers and oceans, which increases primary productivity (Eicher and Rounsefell, 1957; Griggs, 1918). Volcanic activity had a profound effect on humans inhabiting affected areas throughout the millennia (Black, 1981; Dumond, 1979, 2004; Workman, 1979). Short-term effects such as

pyroclastic flows and ash deposits would have been disruptive or lethal, depending on the distance from the volcano. Long-term effects were less of a problem as the land may have been habitable within ten to twenty years after an eruption (Dumond, 1979).

Eight eruptions occurred in the eastern Aleutian arc between 4000 BP and 3400 BP, four of which were caldera forming (VanderHoek and Myron, 2004). The Aniakchak eruption, which occurred in 3400 BP, has been proposed to be one of the causes of the regional hiatus that lasted until approximately 2100 BP (VanderHoek and Myron, 2004). However, the land would have been habitable much sooner than it was re-occupied; therefore, other factors were also likely involved.

Because volcanic ash deposits are subject to aeolian transport and may spread over hundreds of miles, they provide researchers with a means of chronologically connecting a series of archaeological sites. Regional connections are achieved by tracking specific ash deposits in relation to site stratigraphy, radiocarbon dates, and artifact content. Hilton (2000) examined the stratigraphic profile of ash deposits from Takli Island, which is adjacent to Mink Island in Amalik Bay. He found seven tephra horizons; volcanic ash 3/C, which dates to 2800 BP, has the most important archaeological implications. Immediately following this large ash deposit, there is a regional hiatus in the archaeological record that lasted seven to eight hundred years. While the regional abandonment may have initially been caused by the volcanic eruption and subsequent ash deposit, the area would have been habitable sooner than it was reoccupied (Dumond, 1979; Griggs, 1922).

There are eight volcanic ash deposits associated with human occupation at the Brooks River locality on the Bering Sea slope. These volcanic ash deposits range in date from A.D. 1912 (Ash A/Katmai Ash/Novarupta)) to 4100 BP (Ash H) (Nowack, 1968). Ash deposits have been associated with the Brooks River Bluffs Phase (Ash B) and the Brooks River Falls Phase (Ash D) (Cressmann and Dumond, 1962). All other ash deposits (Ash C, E, F, and G) lie in-between the stratigraphic layers associated with the regional cultural phases (Dumond, 1964; Nowack, 1968).

Although volcanoes are absent from the Kodiak Archipelago, periodic eruptions of Alaska Peninsula and Aleutian Island volcanoes spewed ash on the region (Jacob, 1986). When Novarupta erupted in 1912, it deposited a 30-60 cm deep layer of fine ash on parts of Kodiak Island even though it is over 100 miles away (Griggs, 1918). Three volcanic ash strata (Ash 1-3)

have been recognized at the Uyak Site on Kodiak Island. While this stratigraphic sequence is less detailed than are those for the Alaska Peninsula, the ash layers may be used to associate region-wide cultural/volcanic interactions.

Glaciation

The glacial history of the study area is complex and played a significant role in sculpting the landscape (Muhs *et al.*, 1987). Evidence for past glaciation include low ridges of glacial moraine, sloping terraces on valley walls, glacial erratics (isolated boulders deposited miles from the original bedrock), glacially polished bedrock, and U-shaped valleys (Riehle, 2002). Glaciation began in the region during the Late Tertiary period (Hamilton and Thorson, 1983; Harris *et al.*, 1995), and numerous subsequent glacial advances and retreats have occurred since that time (Riehle, 2002).

During the Late Wisconsin glaciation, an ice sheet covered Shelikof Strait and the Kodiak Archipelago, extending to the continental shelf (Karlstrom, 1969; Muhs *et al.*, 1987; Riehle, 2002). Much of the glaciation on the upper Alaska Peninsula was along the Shelikof Strait slope because it received more snow annually compared to the Bering Sea slope (Mann and Hamilton, 1995; Riehle, 2002). Glaciers on the eastern slope extended down mountain valleys and emptied into Shelikof Strait (Riehle, 2002). On the Bering Sea slope, glaciers tended to move only short distances from the mountain valleys onto the Bristol Bay lowlands, where they formed piedmont glaciers. Each piedmont glacier deposited arcuate-shaped terminal moraines. Glacial melt water then transported silt and sand to the coast and formed outwash deposits near the ice margins (Riehle, 2002). On the Bering Sea slope, Late Wisconsin glaciers (Brooks Lake glaciation 10,200 BP) were present near Iliamna and Becharof Lakes (Riehle, 2002), in the Naknek River Valley (Stilwell and Kaufman, 1996), and along the Bristol Bay Lowlands (Riehle, 2002).

Along the outer shelf of the Gulf of Alaska, glaciers began to retreat around 12,000 BP and the coast was ice-free 10,500 BP to 9500 BP (Hamilton and Thorson, 1983; Pewe, 1975). Along the Shelikof Strait coast, smaller glacial advances occurred between 12,000 BP and 10,000 BP and then again between 9800 BP and 9500 BP (Mann and Hamilton, 1995). At the beginning

of the Neoglacial, from 5000 BP to 6000 BP, alpine glaciers in the Gulf of Alaska and Southern Alaska experienced modest advances (Calkin *et al.*, 2001; Crockford and Frederick, 2007; Mann *et al.*, 1998). The coastal area of Shelikof Strait, however, remained relatively ice-free during this period (Crowell and Mann, 1996).

With the notable exception of the southwest portion of Kodiak Island, the Kodiak Archipelago coastline has many glacially carved straits and fjords with branching arms (Karlstrom, 1969). The stratigraphy and geomorphology of this southwest portion is consistent with a prehistoric refugium, or an ice-free area (Karlstrom, 1969). The Kodiak Island refugium was surrounded by ice during the last maximum phases of the last two major regional glaciation episodes (Karlstrom, 1969). During the major glaciation episodes, glaciers extended out to sea and scoured troughs (in-line with the fjords and straits), and deposited debris on the continental shelf up to 30 to 40 miles (Karlstrom, 1969). The effects of widespread glaciation on the Kodiak Archipelago are visible today as deep, wide, and scoured valleys created as glacial ice flowed towards the sea (Heizer, 1956). These glacially sculpted areas provide critical habitat for many of the marine fishes (e.g. Pacific cod, Pacific halibut, sculpins, rockfish, etc.), which compose much of the faunal collections in regional archaeological sites (Rogers *et al.*, 1986).

Local Resource Distributions and Change over Time

Modern Flora

The floral communities of the Shelikof Strait coast and the Kodiak Archipelago are part of a transitional zone, which shifts from the coastal tundra of the Alaska Peninsula and Aleutian Islands to the Pacific coastal forest of British Columbia, Washington, and Oregon (Heusser, 1985). The northeastern end of the Kodiak Archipelago is included in the Pacific coastal zone, and Sitka spruce (*Picea sitchensis*), alder (*Alnus* spp.), blueberry (*Vaccinium* spp.), devils club (*Oplopanax horridus*), and various ferns dominate the landscape (Heusser, 1985; Joint Federal-State Land Use Planning Commission for Alaska, 1973). Sitka spruce began to dominate the floral community in the northeastern portion of the archipelago around 1000 years ago largely because of soil enrichment associated with volcanic ash deposition (Fitzhugh, 1996; Griggs,

1934; Knecht, 1995). The southern limit of Sitka spruce on Kodiak Island lies between Uganik Bay to the west and Ugak Bay to the east, although isolated stands are found as far south as Amber Bay (Griggs, 1934).

The southwestern portion of the Archipelago is covered by a mosaic coastal tundra interspersed with groves of balsam (*Populus balsamifera*) and black poplar (*Populus trichocarpa*) at low elevations in stream drainages. Dwarf alder (*Alnus* spp.), birch (*Betula* spp.), and willow (*Salix* spp.) are found in valleys and on hillsides. Wet tundra bogs and marshes dominate lowland regions whereas alpine tundra dominates higher elevations (Haggarty *et al.*, 1991; Heusser, 1985; Viereck and Little, 1991).

Mink Island, which lies at the mouth of Amalik Bay along the Shelikof Strait coast, is characterized by moist tundra comprised of well-drained grasses, heaths, sedge tussocks, blueberries, and herbaceous plants (Hilton, 2002). Although alders and willows cover approximately 15 % of the adjacent Little Takli Island, Mink Island is devoid of these shrub species. Mink Island is also devoid of conifers, the nearest specimens are located over 20 km away (Hilton, 2002).

The Bering Sea slope is divided into habitat zones based largely on elevation. The alpine zone ranges from about 2000 feet to the highest peaks (7000+ feet), and has similar habitat to that found in arctic regions. Snowfields and glaciers cover a large portion of the alpine zone, and those areas not covered tend to be devoid of vegetation. Little plant life is able to grow on the rocks, sand, and pumice because of the constant bombardment by fierce and icy winds (Hussey, 1971). At slightly lower elevations within the alpine zone, a few hearty species of plants are able to survive. These species grow low to the ground, have thick and leathery foliage, and have extensive root systems. These features help plants to anchor themselves in the rocky substrate and to withstand fierce winds (Hussey, 1971).

Farther downslope, from 2000 to 1200 feet, lies the high tundra zone, in which an assortment of lichens (various), mosses (various), sedges (*Carex* spp.), dwarf alpine birch (*Betula glandulosis*), Arctic wormwood (*Artemisia senjavinensis*), running club moss (*Lycopodium clavatum*), saxifrage (*Saxifraga* spp.), and others create dense mats in locations with sufficient soil formation (Hussey, 1971).

Still lower, in elevations below 2000 feet, the foothills, lake, and coastal plain portions, lies the Hudsonian zone, or low tundra. The low tundra is covered with a dense mat of shrubs, grasses, and flowering plants. A few scattered clusters of white spruce (*Picea glauca*), birch, cottonwood (*Populus* spp.), and alder may be seen interspersed with vast expanses of bog blueberry, bog rosemary (*Andromeda polifolia*), rushes (*Juncus* spp.), grasses (various), and sedges (Hussey, 1971).

In the area north and east of Brooks Lake, lies a transitional zone between the lower and upper tundras. This zone is covered by extensive forests of cottonwood, Kenai birch (*Betula papyrifera kenaica*), green alder (*Alnus viridis*), willow, and white spruce (Hussey, 1971). The forest understory includes bedstraw (*Galium* spp.), bluejoint (*Calamagrostis canadensis*), cucumber-root (*Medeola virginiana*), starflower (*Trientalis borealis*), white hellebore (*Veratrum* spp.), and sedges (Cahalane, 1959).

Local Paleoenvironmental Reconstruction

Various proxy indicators [Sediment cores (pollen, diatoms, stable isotopes), tree-rings, glacial histories, and bone collagen stable isotopes] have been used to reconstruct paleoenvironmental conditions within the study area and the lower Alaska Peninsula (c.f. Ager, 1982; Bigelow, 2000, 2004; Bradley, 1999; Brubaker *et al.,* 2001; Finney *et al.,* 2002; Heusser, 1960, 1985; Jordan and Krumhardt, 2003; Misarti, 2007; Misarti *et al.,* 2009; Nelson and Jordan, 1988; Peteet and Mann, 1994; Wiles and Calkin, 1994; Wiles *et al.,* 1998). These proxy indicators vary in scale, resolution, and time-depth; and therefore, vary in suitability for reconstructing Holocene paleoenvironmental conditions at the Mink Island site.

The most accurate proxy paleoenvironmental data is obtained at the micro-scale-level, which encompass an area less than one mile^2 from the archaeological site (Dincauze, 2000). Other features such as elevation, aspect, and slope must be similar to those found at the archaeological site (Dincauze, 2000). Resolution (number of samples) must also be high enough to track the sometimes-small changes in biological communities. Finally, the proxy paleoenvironmental data must cover the same period that humans occupied the landscape.

Micro-scale-level proxy paleoenvironmental data (pollen) was recorded for Little Takli Island (Bigelow, 2000; Hilton, 2002). The Little Takli Island pollen proxy data was recovered from a peat bog of similar elevation, aspect, slope, and modern vegetation as the Mink Island site (Hilton, 2002). The pollen proxy data has sufficient resolution (21 samples analyzed), and is associated with radiocarbon dates (8 Atomic Mass Spectrometer assays), which firmly place peat bog formation within the Holocene when humans occupied the area (Hilton, 2002). Because the Little Takli Island pollen proxy data meet all of the necessary criteria as a suitable proxy indicator, it will be used here to summarize paleoenvironmental conditions at the Mink Island site.

Results of the Little Takli Island proxy pollen analysis include a description of changes over time of vegetation, general climatic conditions, associated tephra layers, sedimentation rates (when possible), and broad cultural affiliations (Bigelow, 2000; Hilton, 2002). The proxy data indicate that four distinct vegetation zones (1-4) were present at Little Takli Island during the Holocene (Bigelow, 2000). These pollen data generally conform to the four Holocene climatic divisions found along the coastal regions of the Gulf of Alaska (Heusser, 1985; Hilton, 2002; Mann *et al.,* 1998).

Zone 1 (birch/heath shrub tundra): This zone is represented by three dates, in which the earliest date antecedes 7950 BP. Zone 1 represents a warming period following the late Pleistocene glacial retreat, where temperatures are warmer than today but not as warm as in the following zone (Hilton, 2002). Vegetation is dominated by heath (*Ericales*) intermingled with sphagnum and sedges (Cyperaceae). Birch and willow are present in small amounts, and alder is almost non-existent (Bigelow, 2000). Two distinct tephras were encountered in Zone 1 sediments; however, sedimentation rates were low at this time (Hilton, 2002). No cultural artifacts dating to the Zone 1 period have been recovered from the Shelikof Strait coast (Hilton, 2002).

Zone 2 (alder/birch/heath shrub tundra): This zone dates between ca.7950 BP and ca.5450 BP and roughly corresponds with the Hypsithermal interval, which is characterized by significantly warmer and drier summers. Vegetation is represented by a marked increase in alder and a decrease in heaths. Grasses (Poaceae) and birch also increased, while willow and sedges waned. Several taxa of exotic forbs, herbs, and shrubs first made their appearance at

this time (Bigelow, 2000). Two distinct tephras are associated with this zone, and sedimentation rates increased markedly. Zone 2 marks the period when the first humans (Ocean Bay tradition) occupied the Shelikof Strait coast (Clark, 1997).

Zone 3 (birch/alder shrub tundra): This zone dates between ca.5450 BP and ca.2750 BP and represents a transition from the warm and dry Hypsithermal interval to the cool and wet Neoglacial period. The Neoglacial period typically dates between 5500 BP and 3300 BP; however, the Little Takli Island samples are offset by 500 years, dating between 5000 BP and 2500 BP. Zone 3 has been split into two subzones (3a and 3b) based on pollen frequencies (Bigelow, 2000). Subzone 3a dates between ca.5450 BP and ca.3950 BP and is dominated by birch and alder. Heath numbers fluctuate within this subzone; however, their numbers increase at the boundary between 3a and 3b. Sphagnum and sedge numbers are high, while grasses remain unchanged in subzone 3a. Spruce make their first appearance in subzone 3a, however, they appear in small numbers (Bigelow, 2000). Subzone 3b dates between ca.3950 BP and ca.2750 BP and is marked by changes in birch and alder frequencies. Towards the end of subzone 3b, birch decline slightly after a peak at ca.3300 BP, while alder increased in numbers after an initial reduction. Heath and sphagnum decreased significantly in subzone 3b, whereas the number of grasses increased. Two distinct tephras were associated with this zone; however, one was rejected by Hilton (2002: 58, Table 3.1) because radiocarbon dates identified it as too young according to its stratigraphic placement. Like Zone 2, Zone 3 is associated with peoples of the Ocean Bay tradition.

Zone 4 (birch/heath/alder shrub tundra): This zone dates between ca.2750 BP and 38 BP (the 1912 Mt. Katmai eruption). Zone 4 is marked by an increase in birch (which peak at the onset of the Little Ice Age ca.550 BP) and heath taxa, and a discernible decline in alder. There is a marked increase in the number of sphagnum spores at the start of the zone; however, they declined steadily after that period (Bigelow, 2000). Two distinct tephras are associated with zone 4, including a large deposit resulting from the 1912 Mt. Katmai eruption (Hilton, 2002: 56, Figure 3.4). Zone 4 is associated with peoples of the Norton/Kachemak and Thule/Koniag traditions (Clark, 1992b; Dumond, 1987a).

Modern Fauna

Fauna from each sub-region have been combined in this section. Separations are based on ecosystem type (terrestrial, littoral, marine, and riverine) and fauna type (mammals, birds, fishes, and shellfishes).

Terrestrial Ecosystem

The Alaska Peninsula is home to thirty-five species of terrestrial mammals, most notably the Brown Bear (*Ursus arctos*) (United States National Park Service [NPS], 2006). Brown bears may be found in valley bottoms, along salmon streams, or in high-altitude areas in search of berries or ground squirrels (Cahalane, 1959). Brown bear densities are highest in areas surrounding Brooks, Naknek, and Grosvenor Lakes, and along Hallo and Kukak Bays on the Shelikof Strait coast (Cahalane, 1959).

Moose (*Alces alces*) are also numerous, although they are newcomers to the region, arriving during the end of the eighteenth century (Cahalane, 1959; Dumond, 1998; Oswalt, 1967; Sellars and McNay, 1984). Moose have been found in historic village sites (Kukak, Kaguyak, and Savonoski) from both sides of the Aleutian Range (Cahalane, 1959; Dumond, 1998; Oswalt, 1967; Sellars and McNay, 1984).

Caribou (*Rangifer tarandus*) are also on both sides of the Alaska Peninsula, although based on archaeological and historical evidence, they were once much more abundant (Cahalane, 1959). Bones from caribou have been found at archaeological sites on both sides of the Aleutian Range, but they are more common on the Bering Sea slope (Skoog, 1968). By the early 1900's, commercial hunting greatly reduced caribou numbers in the region (Hussey, 1971; Skoog, 1968).

Other fur-bearing mammals include red fox (*Vulpes vulpes*), river otter (*Lutra canadensis*), beaver (*Castor canadensis*), short-tailed weasel (*Mustela erminea*), least weasel (*Mustela nivalis*), mink (*Mustela vison*), wolverine (*Gulo gulo*), wolf (*Canis lupus*), lynx (*Lynx canadensis*), porcupine (*Erethizon dorsatum*), Alaskan Arctic hare (*Lepus americanus*); varying

hare (*Lepus* spp.), marten (*Martes americana*), and Arctic ground squirrel (*Spermophilus parryii*) (Cahalane, 1959).

Terrestrial animals indigenous to the Kodiak Archipelago are relatively scarce because of biogeographic isolation after the last glaciation. Of the sixteen land mammals present on the island, only eight of them are indigenous, including northern vole (*Microtus oeconomus*), ground squirrel, red fox, brown bat (*Myotus lucifagus*), ermine (*Mustela erminea*), river otter (*Lutra canadensis*), and brown bear (*Ursus arctos*) (Haggarty *et al.*, 1991; Rausch, 1969). Other terrestrial animals were either introduced by prehistoric occupants (domesticated dog *Canis familiaris*) or migrated across Shelikof Strait (swimming or on a raft as flotsam) shortly after deglaciation from the Alaska Peninsula (Fitzhugh, 1996). Russian colonists introduced the Sitka black-tailed deer (*Odocoileus hemionus*) and beaver, while more recently; Americans introduced mountain goat (*Oreamnos americanus*), caribou, elk (*Cervus canadensis*), muskrat (*Ondatra ziebethicus*), Alaskan Arctic hare, and red squirrel (*Tamiasciurus hudsonicus*) (Haggarty *et al.*, 1991; Rausch, 1953, 1969).

Bird taxa are numerous and diverse in all three sub-regions of the study area; however, not every available taxon was used by historic and prehistoric occupants. Those taxa regularly used for food, clothing, and bone tools will be the focus of this section. Bird taxa are presented by general type (migratory waterfowl, year-round waterfowl, and upland game birds) to aid with organization.

The Bering Sea slope is within a preferred waterfowl migratory corridor, therefore, bird numbers are seasonally high (Dumond, 1987a). The dominant migratory taxa include mallards (*Anas platyrhynchos)* and red-breasted mergansers (*Mergus serrator*). Waterfowl use the many bays, lakes, and lagoons as staging grounds on their way through the region, and the many lakes provide nesting areas for ducks (Dumond, 1987a).

Dominant waterfowl taxa along the Alaska Peninsula and the Kodiak Archipelago may be found year-round in the lake and marshy wet tundra habitats (Fitzhugh, 1996). Year-round residents of the marsh wetlands include whistling swans (*Cygnus columbianus*), green-winged teals (*Anas crecca*), northern Pintails (*Anas acuta*), and mallards. Goldeneyes (*Bucephala* spp.), buffleheads (*Bucephala albeola*), mergansers (*Mergus* spp.), harlequin ducks (*Histrionicus histrionicus*), scoters (*Melanitta* spp.), and emperor geese (*Chen canagica*) spend the winters

near brackish lagoons and in the lower reaches of river valley; where they subsist on seaweeds, fish, crustaceans, mollusks, and other small invertebrates. These taxa move to the north or other coastal regions during other seasons (Fitzhugh, 1996).

Upland game birds such as rock ptarmigan (*Lagopus mutus*), willow ptarmigan (*Lagopus lagopus*), and spruce grouse (*Dendragapus canadensis*) inhabit coastal forest zones, shrub tundra and alpine tundra of both coasts of the Alaska Peninsula (Cahalane, 1959; Hussey, 1971). While spruce grouse are found in the same types of places within the Kodiak Archipelago (Fitzhugh, 1996).

Littoral Ecosystem

The littoral ecosystem is the near-shore environment that extends from the base of the intertidal zone to the shoreward terrestrial vegetation edge. Within the region, this ecosystem may consist of precipitous cliff bands, stacks, and rock piles in exposed areas; mixed sand, pebble, and cobble beaches in transitional areas; and mud flats at the heads of bays, lagoons, and coves (Fitzhugh, 1996).

Certain terrestrial mammals periodically visit the near-shore environment. Bears frequent the beaches during the summer and fall. Red foxes also use the beaches on a regular basis during low tide in search of shellfish, octopus, and dead animals beached on the shore (Fitzhugh, 1996).

Some of the more rocky and inaccessible coastal areas contain haul-out and rookery sites for resident sea mammals including harbor seals (*Phoca vitulina*) and Steller sea lions (*Eumetopias jubatus*). Sea mammals prefer locations that are protected against marine predators (humans and killer whales *Orcinus orca*) and terrestrial predators (brown bears) (Calkin, 1986). Steller sea lions, harbor seals, and sea otters (*Enhydra lutris*) are year-round residents, but Northern fur seals (*Callorhinus ursinus*) are only available seasonally as they migrate past Kodiak Island (usually a considerable distance off shore) to and from their summer breeding grounds in the Pribilof Islands (Clark, 1986; Crockford and Frederick, 2007).

Sea otters are found in the waters surrounding the Kodiak Archipelago and in Shelikof Strait, but are absent from the study area portion of the Bering Sea (Dumond, 1987a). Sea

otters congregate in the water near the Tugidak Islands, Afognak Island, and the northeastern and southwestern portions of Kodiak Island. Sea otters are evenly distributed along Shelikof Strait (Calkin, 1986). Current sea otter numbers are small because of over-hunting mostly during historic times (Cahalane, 1959).

Steller sea lions are common along Shelikof Strait (especially Amalik, Kuliak, and Dakavak Bays) and in the water surrounding the Kodiak Archipelago (Cahalane, 1959; NPS, 1968). Although they are present in the Bering Sea, they are not typically found along the study area coastline (Dumond, 1987a). Steller sea lions use haulout locations as rookeries and may be easier to obtain during breeding season (Calkin, 1986).

Harbor seals are common in Shelikof Strait (Kinak, Kukak, Amalik, and Katmai Bays), the water surrounding the Kodiak Archipelago (Tugidak Island), and the Bering Sea (Egegik Bay) (Cahalane, 1959; Calkin, 1986; Dumond, 1987a). Harbor seal use a variety of haul out locations, allowing for greater numbers in the region (Calkin, 1986).

Walruses are in the Bering Sea but are nearly absent from Shelikof Strait and the waters surrounding the Kodiak Archipelago (Calkin, 1986). Walruses may be harvested during the winter months on the southern limit of the Bering Sea ice pack (Dumond, 1987a, 1998).

Northern fur seals are found offshore in the Bering Sea and the Kodiak Archipelago during the spring (Calkin, 1986). Because of their offshore location and seasonal availability, they are less abundant in the archaeological record of the region (Calkin, 1986).

Several species of toothed and baleen whales migrate into the Gulf of Alaska during the spring and summer. Gray whales *(Eschrichtius robustus)*, humpback whales (*Megaptera novaeanglia*), Minke Whales (*Balaenoptera acutorostrata*), killer whales, and Dall's porpoises (*Phocoenoides dalli*) may be found in nearshore locations adjacent to the Littoral ecosystem in Shelikof Strait and in the waters surrounding the Kodiak Archipelago.

The Shelikof Strait coast and the Kodiak Archipelago are home to a number of seabird taxa that nest along steep cliffs or grassy slopes (DeGange and Sanger, 1986). Cormorants (*Phalacrocorax* spp.), tufted puffins (*Fratercula corniculata*), scoters (*Melanitta* spp.), murrellets (*Brachyramphuis marmoratus, Brachyramphuis brevirostris*), murres (*Uria aalge, Uria lomvia*), guillemots (*Cepphus grylle, Cepphus columba*), black-legged kittiwakes (*Rissa tridactyla*), terns (*Sterna paradisaea, Sterna aleutica*), gulls (*Larus glaucescens, Larus canus*), and eagles

(*Haliaeetus albicilla, Haliaeetus leucocephalus*) are year-round residents that inhabit rocky islets and cliffs (DeGange and Sanger, 1986; Sowles *et al.*, 1978). Densities are higher along the Kodiak Archipelago and the drowned coastline along the Shelikof Strait coast (Amalik, Katmai, and Kukak Bays). Numbers are lower between Cape Douglas and Cape Nukshak, probably because the area lacks suitable cliffs and grassy slopes to for use as nesting sites (DeGange and Sanger, 1986).

Within the Kodiak Wildlife refuge, an estimated 140 seabird colonies, comprised mostly of black-legged kittiwakes and tufted puffins are present (FWS, 1987). Along the Shelikof Strait coast (Katmai, Kukak and Amalik Bays), large seabird colonies consisting primarily of tufted puffins, glaucous-winged gulls (*Larus glaucescens*), and pigeon guillemots (*Cepphus columba*) are present (Cahalane, 1959). Because the Bering Sea coastline is low and sloping, it lacks suitable terrain in which breeding colonies may be located. However, cormorants established a small breeding colony near the mouth of the Egegik River, and glaucous-winged gulls have a small breeding colony near the mouth of the Kvichak River (Hunt *et al.*, 1981).

Prehistoric and historic occupants (Sugpiaq and Alutiiq) of the region harvested seabirds to be used for food and material resources (Davydov, 1976). The late spring nesting season provided an abundant source of protein in the form of eggs. Parkas were made from guillemot, cormorant, murre, and puffin feathers; and puffin beaks were used for clothing decoration and to make rattles (Davydov, 1976).

The abundance and diversity of fish taxa found in Shelikof Strait is similar to that found in the waters surrounding the Kodiak Archipelago, but is dissimilar to that of the Bering Sea (Appendix B) (Bakkala *et al.*, 1981; Rogers *et al.*, 1986; Straty, 1981). Because the waters of the Bering Sea are colder and the coast possesses fewer indentations and bays, it does not support the same level of diversity as in the North Pacific Ocean, although many of the same demersal fish taxa are present (Bakkala *et al.*, 1981).

Near-shore fishes inhabit the shallow subtidal and intertidal zones surrounding the Kodiak Archipelago and along the Shelikof Strait and Bering Sea coasts. In the spring, spawning herring (*Clupea pallasii*) enter the area and provide a rich source of calories in the form of roe attached to seaweed, which washes on to shore. Although herring spawn in Bristol Bay, the major spawning grounds are in waters to the south and east (Wepestad and Barton, 1981).

In summer and fall, salmon enter near-shore areas awaiting the right conditions to migrate up spawning streams (Rogers *et al.*, 1986). Other near-shore taxa include rockfish (*Sebastes* spp.) and greenling (*Hexagrammos* spp.) (Rogers *et al.*, 1986). Offshore demersal and semi-demersal fish also migrate into near-shore waters during spring and summer to spawn. During this time, fishing from shore with hook and line or nets may produce salmon, Pacific cod (*Gadus macrocephalus*), walleye pollock (*Theragra chalcogramma*), sculpin (Cottidae), herring, juvenile halibut (*Hippoglossus stenolepis*), yellowfin sole (*Limanda aspera*), rock sole (*Lepidopsetta* spp.), and starry flounder (*Platichthys stellatus*), among others (Rogers *et al.*, 1986).

The near-shore zone of the Kodiak Archipelago and the Shelikof Strait coast has a diverse range of substrate types, and they are able to support abundant and diverse shellfish taxa (Fitzhugh, 1996; Foster, 2003). Because the Bering Sea substrate largely consists of fine-grained sediments such a mud, sand, and gravel, it is able to support much less diverse shellfish taxa. Bering Sea shellfish are also affected by scouring from sea ice during winter months, which reduces abundance. Finally, extensive mudflats along the Bering Sea coast make harvesting shellfish difficult. Therefore, shellfish are less numerous in the archaeological record from the Bering Sea slope as compared to the other sub-regions (Clark, 1977; Dumond, 1987a).

Along the Shelikof Strait coast and the Kodiak Archipelago, blue mussels (*Mytilus eduliss*) and barnacles (*Balanus* spp.) dominate the middle zone of the rocky, exposed intertidal reef, whereas chitons (*Katherina tunicata, Mopalia ciliate, Tonicella lineate*) and limpets (*Acmaea* spp.) dominate the lower intertidal substrate. Whelk (Muricidae), triton (Raneillidae), sea urchins (*Strongylocentrotus* spp., *Allenocentrotus fragilis*), and periwinkle (Littorinidae) inhabit shallow subtidal zones and deep tide-pools. Butter clams (*Saxidomus giganteus*), Pacific littleneck clams (*Protothaca staminea*), cockles (*Clinocardium* spp.), goeyducks (*Panope generosa*), horse clams (*Tresus capax*), and soft shell clams (*Mya* spp.) inhabit the more protected low-energy shores. Razor clams (*Siliqua alta*) and Alaska surf clams (*Spisula polynyma*) dominate high-energy sand and mud beaches (Fitzhugh, 1996, 2003).

Marine Ecosystem

The marine ecosystem surrounding the Kodiak Archipelago is one of the richest in the world because it is in an upwelling center that draws free nutrients from the terminus of a density-driven deep-water current (Reeburgh and Kipphut, 1996; Reed and Shumacher, 1986). When the upwelling nutrients reach the photosynthetic zone near the surface, they become incorporated into the bloom, which serves as the primary production base (Hood, 1986). Nutrients may enter the marine ecosystem via other mechanisms that include fresh water run-off from terrestrial sources, earthquake induced mass-wasting, and volcanic ash deposition (Fitzhugh, 1996).

Harbor seals, northern fur seals, sea lions, and sea otters may be found in small groups or individually in offshore locations. They may also be found in near-shore locations in bays, coves, and off stream mouths and points in the waters surrounding the Kodiak Archipelago and the Shelikof Strait coast (Calkin, 1986; Fitzhugh, 1996). Blue whales (*Balaenoptera musculus*), fin whales (*Balaenoptera physalus*), sei whales (*Balaenoptera borealis*), sperm whales (*Physter catodon*), giant bottlenose whales (*Berardius bairdi*), and right whales (*Eubalaena glacialis*) may be found in offshore locations near the Kodiak Archipelago. A small beluga whale (*Delphinapterus leucas*) population is present in Cook Inlet, and may have frequented the Kodiak Archipelago in prehistoric times (Crowell, 1994b; Fitzhugh, 1996; Henning *et al.*, 1978).

Fishes are prominent in the marine ecosystem surrounding the Kodiak Archipelago, Shelikof Strait coast, and the Bering Sea coast. Full-grown Pacific halibut, which may exceed 300 pounds, inhabit deep waters on the continental shelf as much as five kilometers off-shore during the fall and winter months. They migrate into shallower waters of bays and straits during the spring and summer to spawn (Kessler, 1985; Rogers *et al.*, 1986).

Large walleye Pollock, Pacific cod, Pacific tomcod (*Microgadus proximus*), great sculpins (*Myoxocephalus polycantocephalus*), yellow Irish lords (*Hemilepidotus jordani*), flathead sole (*Hippoglossoides elassodon*), and sablefish (*Anaploploma fimbria*) inhabit the bottoms of deep bays and straits, and the continental shelf. Juveniles of these species inhabit the near-shore locations until they reach maturity (Rogers *et al.*, 1986). Rockfish, sculpins, lingcod (*Ophiodon elongatus*), Atka mackerel (*Pleurogrammus monopterygius*), and greenlings prefer exposed,

rocky environments near kelp beds (Rogers *et al.*, 1986). Pacific ocean perch (*Sebastes alutus*), yellowfin sole, starry flounder, and rock sole are most common in shallow intertidal zones, often near river mouths (Rogers *et al.*, 1986). Capelin (*Mallotus villosus*), Pacific herring, Pacific sand lance (*Ammodytes hexapterus*), and juveniles of many other species are the major forage fishes (Rogers *et al.*, 1986).

Riverine Ecosystem

The riverine ecosystem of the Kodiak Archipelago and both sides of the Alaska Peninsula is dominated by anadromous fish taxa that include the six Pacific salmon species: king salmon (*Oncorhynchus tshawytshca*), coho salmon (*Oncorhynchus kisutch*), sockeye salmon (*Oncorhynchus nerka*), chum salmon (*Oncorhynchus keta*), pink salmon (*Oncorhynchus gorbuscha*), and steelhead/rainbow trout (*Oncorhynchus mykiss*). Dolly Varden (*Salvelinus malma*) are also present (Barsch, 1985; Cressman and Dumond, 1962; Kessler, 1985; Rogers et al., 1986; Straty, 1981).

The important salmon spawning streams on the Bering Sea coast include Alagnak, Egegik, King Salmon, Kvichak, and Naknek Rivers (United States Department of Interior Alaska Planning Group, 1975). Peak spawning occurs from late spring/early summer (king salmon), summer (pink, chum, and sockeye salmon), and early fall (coho salmon) (Straty, 1981).

Salmon spawning streams on the Shelikof Strait coast are less numerous, because rivers there are typically shorter and more steep; although the Chignik River houses a substantial run of sockeye salmon (Dumond, 1987a). The most common salmon species found along the Shelikof Strait coast are pink and chum because they are hardy, and can spawn under conditions that inhibit other species (Dumond, 1987a). The fry of these two salmon species migrate out of the river environment into the shallow near-shore waters within days or weeks of hatching. Whereas king, coho, and sockeye salmon spawn in river environments, their fry stay in the rivers for one year, and after that time, they migrate into the shallow near-shore environment as smolts (Barsch, 1985). Because pink and chum salmon spend much less time associated with the river environment, they are able to spawn in smaller streams with lower water discharge.

King, coho, and sockeye salmon require larger, longer, and more productive rivers and streams with lakes to reach maturation (Barsch, 1985).

All six species of salmon are found on the Kodiak Archipelago, and in the larger rivers such as the Karluk and Ayukulik, fish may be found year-round (Knecht, 1995), although they are more numerous during the summer and fall spawning season. King and sockeye spawn as early as late May and coho may not spawn in some locations until November (FWS, 1987). In the smaller rivers, fish abundance will vary depending on the season, and the species of anadromous fish that inhabit the water, although pink and chum salmon will be more numerous (Barsch, 1985).

Other fish that inhabit the lakes and streams of the Bering Sea slope include lake trout (*Salvelinus namaycush*), rainbow trout, Dolly Varden, Arctic grayling (*Thymallus arcticus*), northern pike (*Esox lucius*), round whitefish (*Prosopium cylindraceum*), humpback whitefish (*Coregonus pidschian*), Arctic char (*Salvelinus alpinus*), and longnose sucker (*Catostomus catostomus*) (Cressman and Dumond, 1962).

Chapter 4. Regional Cultural History

Introduction

This chapter presents the regional archaeological history, the regional cultural history, and the Mink Island site (XMK-030) context. Regional archaeological research is divided into three temporally distinct periods (Early, Initial Academic, and Late Academic) and is presented by sub-region when possible. The regional cultural history is divided into seven temporally distinct traditions (Paleoarctic, Ocean Bay, Northern Archaic, Arctic Small Tool, Kachemak, Norton, and Thule) that span the entire region. The Mink Island site context provides descriptions of the site location, excavation strategy, lithostratigraphic divisions, radiocarbon dates, temporal/cultural zonation, features, and fishing-related artifacts.

The purpose of this chapter is to place the Mink Island site within the cultural context of the region. The regional archaeological history outlines the locations that have been surveyed and helps to identify those locations that warrant additional investigation. The cultural history section uses data obtained from site locations, features, artifacts, and faunal remains to make inferences about changing lifeways. By comparing the Mink Island fish bone data to the data from other regional sites, it is possible to determine where Mink Island fits within the regional pattern.

Regional Archaeological History

Following Tennessen (2009), archaeological research occurred during several broad temporal periods (Early, Initial Academic, and Late Academic). These periods loosely follow those developed by Davis et al. (1981) for the western Gulf of Alaska, but have been adjusted to reflect the specific research history of the study area.

The Early Period

The Early Period dates from the beginning of historic contact (1741) until the early 1900s. Explorers, missionaries, and traders were largely responsible for recording these early anthropological descriptions (Black, 1992, 2004a, 2004b; Crowell, 1997; Partnow, 2001; Townsend, 1974). Georg Wilhelm Steller recorded the first anthropological descriptions of Aleut people during Bering's second expedition in 1741 (Collins, 1984). Other anthropological descriptions were collected by members of the Russian Orthodox Church and census workers associated with the 1867 purchase of Alaska from Russia (Black, 2004b; Collins, 1984; Partnow, 2001; Townsend, 1974). Because the recording of ethnographic information was not the primary goal, anthropological descriptions during the Early Period tended to be short (Partnow, 2001).

The Initial Academic Period

The Initial Academic Period dates between the early 1900's and the early 1940's. The goal of anthropological research conducted during the Initial Academic Period was to learn about the native occupants of the region. Ales Hrdlicka of the Smithsonian Institution led the earliest Initial Academic Period research within the study area (Hrdlicka, 1933, 1935, 1936, 1937, 1944). Research took place during the summers from 1931 to 1936 at the Uyak Site, in Larsen Bay on Kodiak Island. Hrdlicka's goal was to collect large numbers of human remains to test hypotheses pertaining to the origins of North American biological variation. While in the Uyak Bay region, Hrdlicka and his crew also surveyed coastal areas surrounding the Bering Sea and Shelikof Strait (Clark, 1992a; Heizer, 1956; Hrdlicka, 1944; Loring and Prokopec, 1994).

Around the same time that Hrdlicka was working on Kodiak Island, Frederica de Laguna was completing archaeological research in Prince William Sound and Cook Inlet (de Laguna, 1934, 1956). While her research area is outside of the current study area, it is important to the development of the regional culture history. De Laguna's research determined that the Dena'ina occupation in Cook Inlet during historic times was preceded by an earlier cultural expression, which she termed the Kachemak culture (de Laguna, 1934). Subsequent researchers

would build upon De Laguna's work, and the cultural expression eventually became known as the Kachemak tradition (Workman, 1980).

The Late Academic Period

Regional archaeological investigations increased during the Late Academic Period when State and Federal government agencies worked in concert with Native peoples and academic institutions to manage cultural resources. During the Late Academic Period, complex interactions between environmental conditions and human cultural adaptations were explored. The data obtained during the Late Academic Period was used to refine the regional culture history sequence.

Late Academic Period archaeological research within the upper Alaska Peninsula began in 1953 with the development of the Katmai Project (Norris, 1996). In 1953, Wilbur A. Davis and James W. Leach surveyed three native villages (Katmai, Kukak Bay, and Old Savonoski) that had been abandoned after the 1912 eruption of Novarupta. Davis and Leach also investigated the Kaguyak (Douglas Village) and the Brooks River fishing camp during that year (Norris, 1996; Oswalt, 1955). In 1954, archaeological investigations conducted by Wendell Oswalt located sites near Cape Douglas, Devils Cove, Kaflia Bay, Grosvenor Camp, Kulik Camp, and Kukaklek Lake. Excavations at Kaflia Bay uncovered artifacts that would later be associated with the Ocean Bay tradition (Oswalt, 1955).

From 1960-1961, Luther S. Cressman (University of Oregon Department of Anthropology) led joint National Park Service (NSP), National Science Foundation (NSF), and Bureau of Commercial Fisheries (BCF) funded research at Brooks Camp on the Bering Sea slope of the peninsula in attempts to record long-term changes in salmon productivity (Dumond, 1981). Archaeological survey was also conducted during this time in other nearby locations including the Naknek drainage (Dumond, 1981), the Ugashik drainage (Henn, 1978), and on the Shelikof Strait coast (Clark, 1977). From 1966-1967, the National Geographic Society (NGS) funded additional research at Brooks River with the aim of excavating and reconstructing a house feature at the site, however, it proved to be unsuitable for such purposes (Dumond, 1981). Because of research conducted in the 1960's, it became clear that the cultural sequence

of the Bering Sea slope was different from the sequences of the Kodiak Archipelago and the Shelikof Strait coast (Dumond, 1981; Henn, 1978).

In 1975, NPS placed some of Katmai National Monument's most important sites (Brooks River, Kaguyak, Kukak, Old Savonoski, Savonoski River, Takli Island, and sites near Cape Chiniak and Dakavak Bay) on the National Register of Historic Places (NRHP), which prompted additional archaeological work in the region. They recognized that a few areas contained an especially high number of concentrated archaeological sites and deserved special attention and protection. In 1978, the Brooks River region, which encompasses twenty sites, was designated as an Archaeological District. The same region was further designated a National Historic Landmark in 1993 (Tennessen, 2009; United States Department of the Interior, 2011). The Takli Island Archaeological District was listed on the National Register of Historic Places in 1953 and is now part of the larger Amalik Bay National Historic Landmark (NHL) archaeological district, listed on the Register in 2005. The Amalik Bay NHL recognition hinged on the significance of the Mink Island site, brought to light by the 1997-2000 excavations.

Research continued on the Alaska Peninsula during the mid-1980s when Dumond (1987b) surveyed the Izembek, Alaska Peninsula, Becharof, and Togiak National Wildlife Refuges in an attempt to create a predictive model of archaeological site locations. Dumond (1987b) determined that there were a disproportionately low number of archaeological sites on the Pacific coast of the Alaska Peninsula as compared to other regions in the western Gulf of Alaska even though that region contained an equal number of available resources.

The 1989 *Exxon Valdez* oil spill prompted a great deal of archaeological research in the region (Dekin *et al.*, 1993; Erlandson *et al.*, 1992; Haggarty *et al.*, 1991; Mobley *et al.*, 1990). Roughly 5000 kilometers of coastline ranging from Prince William Sound to the Alaska Peninsula and the Kodiak Archipelago were surveyed for archaeological sites (Erlandson *et al.*, 1992). Because of this disaster-mediated research, the number of sites recorded in the region more than doubled (Erlandson *et al.*, 1992). Additionally, the disaster-mediated research allowed researchers to make region-wide statements about settlement patterns and archaeological site densities (Tennessen, 2009).

In 1994, joint Smithsonian Institution/NPS research was conducted on the Katmai National Park and Preserve portion of the Shelikof Strait coastline (Crowell and Mann, 1996;

National Science Foundation, 1998). The goal was to build upon Dumond's (1987b) research, and create a regional model that compared prehistoric settlement patterns in relation to distribution of subsistence resources, glacial action, and Holocene sea level changes (Crowell and Mann, 1996; National Science Foundation, 1998). At least 90 pre-contact and historic period settlements between Cape Douglas and Katmai Bay were identified because of this and previous research (Crowell and Mann, 1996). In 1996, the Katmai Coastal Site Protection Project was initiated to monitor and record archaeological sites that had been earlier recorded (Crowell and Mann, 1996). Archaeological excavations at the Mink Island site were conducted at this time (Hilton, 1998, 2002; Schaaf, 2009; Tennessen, 2009).

Late Academic Period work continued in the Kodiak Archipelago with the inception of the University of Wisconsin's Aleut-Koniag Prehistory Project (1961-1964) (Clark, 1992a). The goal of this project was to document the cultural histories, ethnic and cultural relationships, and the ecology of the Eastern Aleutian Islands and the Kodiak Archipelago (Clark, 1992a). During this project, excavations at the Rolling Bay site on southern Sitkalidak Island (Clark, 1974a; McHugh, 1962) helped to define the Koniag period (Fitzhugh, 1996). Research in 1962 was focused at Three Saints Bay and a Russian outpost (Clark, 1985). Beneath the historic Russian materials, researchers found remains associated with the Three Saints Bay phase of the Kachemak tradition (Clark, 1970). Research in 1963 was focused at Kiavak Bay, where Old Kiavak phase materials were recovered. Like the Three Saints Bay phase, the Old Kiavak phase is also linked with remains recovered from Kachemak Bay and the Kachemak tradition (Clark, 1970). During that same year, a multi-component site was discovered at Ocean Bay on Sitkalidak Island. At Ocean Bay, the upper component was dominated by an early ground-slate industry (Ocean Bay II phase), and the lower component was dominated by a chipped stone industry (Ocean Bay I phase) (Clark, 1974b, 1979). With the addition of the Ocean Bay phases, the basic culture history framework of the Kodiak Archipelago was established (Fitzhugh, 1996).

Archaeological research was spurred in the Kodiak Archipelago after the 1964 earthquake when tectonic movements altered the landscape and affected regional archaeological deposits (Clark, 1992a; Gilpin, 1995; Pflaker, 1969). During the last season of the Aleut-Koniag Prehistory and Ecology Project, the effects of the earthquake on Crag Point and Chirikof Island were recorded (Clark, 1992a; Workman, 1966, 1969). Material culture recovered

from Chirikof Island was unique; it appeared to be a combination of cultural traditions from Kodiak Island, the Aleutian Islands, and the Alaska Peninsula (Workman, 1966, 1969). Archaeological investigations at Crag Point, in Anton-Larsen Bay near the town of Kodiak, contained late Kachemak tradition materials that helped to define the Kodiak variant of the tradition (Clark, 1970).

During the late 1970s and the early 1980s, archaeological work on the Kodiak Archipelago was mostly aimed at mitigating the impacts of building, hydroelectric plant, and community airstrip projects (Cassedy and Dekin, 1983). However, the U.S. Fish and Wildlife Service and the Bureau of Indian Affairs also funded archaeological investigation on Kodiak during this period (Clark, 1992a; Crozier, 1987, 1989; Yesner, 1989).

Richard Jordan implemented the Kodiak Archaeological Project in 1983. During this project, excavations began at sites in the Karluk Lagoon in southwest Kodiak, where an unbroken cultural sequence ranged from the Historic period to the Ocean Bay period (Jordan and Knecht, 1988). This research spurred a lot of interest in the archaeological sequence of Kodiak Island, and researchers (Rick Knecht, Glenn Sheehan, Kevin Smith, Aaron Crowell, Amy Steffian, and Thomas Amorosi) began a surveying and mapping project of Uyak Bay and the Karluk River, Lake, and Lagoon (Crowell, 1986; Jordan and Knecht, 1988). Additional work was conducted at Crag Point, the Karluk One site, and the Uyak site at this time (Fitzhugh, 1996; Steffian, 1992a).

In 1987, the Kodiak Area Native Association (KANA) created a Kodiak regional cultural heritage program, which was led by Rick Knecht (Pullar, 1992). The Alutiiq Culture Center was created from this program with an aim to coordinate archaeological research, study the Alutiiq language, collect oral histories, record traditional knowledge, and exhibit archaeological and ethnographic collections (Fitzhugh, 1996). At this time, Knecht conducted archaeological research throughout the Kodiak Archipelago (Knecht, 1995). Between 1988 and 1990, Philomena Hausler-Knecht excavated a large section of Rice Ridge in Chiniak, and discovered well-preserved faunal materials and organic materials (fishhooks, needles, bone harpoon points, throwing board darts) from Ocean Bay I and II levels (Knecht, 1995; Hausler-Knecht, 1991).

The 1989 *Exxon Valdez* oil spill also coated major sections along the Kodiak Archipelago coastline with oil (Dekin *et al.*, 1993; Erlandson *et al.*, 1992; Haggarty *et al.*, 1991; Mobley *et al.*,

1990). After two years of archaeological survey, the number of archaeological sites that were recorded along the coast of the Gulf of Alaska doubled (Erlandson *et al.*, 1992; Haggarty *et al.*, 1991). Because of a 1.5 million dollar grant given to the Kodiak Area Native Association as part of the legal settlement from the *Exxon Valdez* Company, the Alutiiq Museum and Archaeological Repository was created (Alutiiq Museum Accessed online on December 24th 2010).

A number of important dissertations (e.g. Fitzhugh, 1996; Knecht, 1995; Kopperl, 2003; Partlow, 2001; West, 2009) have been produced because of more recent work in the Kodiak Archipelago. Fitzhugh's archaeological survey of Sitkalidak Island allowed him to create a model for the development of cultural complexity, which included descriptions of technological innovations, settlement patterns, and the initial colonization of the Kodiak Archipelago (Fitzhugh, 1996, 2001, 2002, 2003, 2004). Both Kopperl's (2003) and Partlow's (2001) dissertations provide insights into resource intensification in the region.

The many years of archaeological research within the region led to the development of a regional cultural history sequence. The culture history sequence is organized by regional (e.g. traditions) and sub-regional (e.g. phases) differences in material culture (e.g. artifacts, features, faunal remains, etc.). Because a goal of this dissertation is to determine where Mink Island fits within the regional cultural sequence, the data presented within the following section is presented at the regional-level. Sub-regional variations are also discussed; however, they receive less attention.

Regional Culture History

The upper Alaska Peninsula (Shelikof Strait coast and Bering Sea slope) and the Kodiak Archipelago regions have been occupied many millennia by maritime-focused cultures (Workman, 1980; Yesner, 1992). These maritime-focused people are related to each other and have been influenced by other cultures from adjacent regions (e.g. Aleuts, Bering Sea Eskimos, Athapaskans, and Tlingit) (Workman, 1980). The regional prehistory is complex and is marked by gaps in the archaeological record, shortened cultural sequences, and periods of accelerated culture change (Workman, 1980). The high degree of regional variation has made the development of a single region-wide culture history sequence unmanageable. To deal with

regional variability, researchers have divided the cultural sequences into sub-regional phases (e.g. Clark, 1992a, Dumond, 2005, etc.). However, separating the cultural phases by sub-regional variants may obscure region-wide connections. To overcome some of these problems, the culture history sequence is presented by cultural tradition. Individual sub-regional phase variants and radiocarbon age ranges are presented within the tradition descriptions. All radiocarbon age ranges are presented as uncalibrated years before present (BP) unless otherwise specified (Figure 4.1).

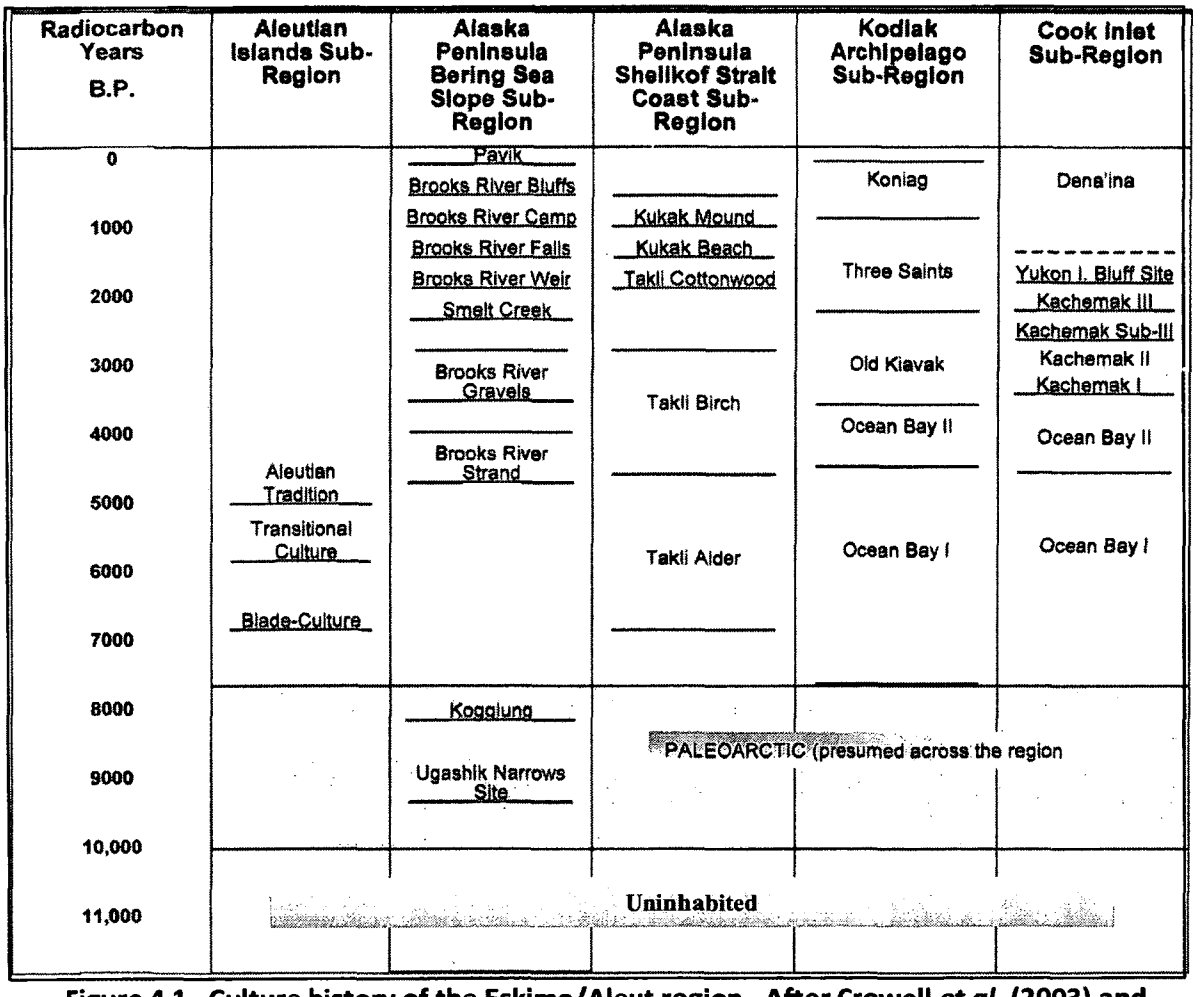


Figure 4.1. Culture history of the Eskimo/Aleut region. After Crowell *et al.* (2003) and Dumond and Bland (1995).

Paleoarctic tradition

The Paleoarctic tradition is represented by core and blade technology, which dates between 11,000 and 7500 BP (Haggarty *et al.*, 1991). Paleoarctic tradition sites are found in coastal and interior locations from Siberia to Southeast Alaska (Ackerman, 1984; Anderson, 1968, 1970, 1984; Dikov, 1968; Dumond, 1977, 1984a, 1984b, 2005). Paleoarctic tradition sites have been found at Onion Portage, Dry Creek, Trail Creek, the Brooks Range, and on the North Slope in the Alaskan Interior (Anderson, 1970, 1972, 1984; Davis *et al.*, 1981; Powers and Hoffecker, 1989). Coastal or near coastal Paleoarctic tradition sites have been found at Anangula in the eastern Aleutians; Koggiung and Ugashik Narrows on the northern Alaska Peninsula; Beluga Point in upper Cook Inlet; and Groundhog Bay, Hidden Falls, Chuck Lake, Thorne River, Lawn Point, Kasta, and Namu in Southeast Alaska and British Columbia (Ackerman *et al.*, 1979, 1985; Aigner *et al.*, 1976; Anderson, 1970, 1972, 1984; Davis, 1989; Davis *et al.*, 1981; Holmes *et al.*, 1989; Powers and Hoffecker, 1989; Reger, 1977, 1981).

Within the study area, Paleoarctic tradition sites are found at the Mink Island (Shelikof Strait coast), Ugashik Narrows (Bering Sea slope), and Graveyard Point (Bering Sea slope) sites (Dumond, 1987a; Schaaf, 2009). No Paleoarctic tradition sites have been found in the Kodiak Archipelago. Whether Paleoarctic tradition peoples inhabited Kodiak Island is unclear because the combined effects of earthquakes, tsunamis, subsidence, sea level rise, and storminess may have erased all evidence of these early habitations (Crowell *et al.*, 2003). However, the archipelago would have been sufficiently free of Pleistocene ice sometime between 10,000 and 11,000 years ago (Clark, 1992b).

Recent excavations at the Mink Island site uncovered large basalt blades, a few microblades, a broken bifacial point, and a few simple ochre-encrusted tools (Schaaf, 2009). A small, ochre-covered shallow basin house floor is also associated with the Paleoarctic tradition component (Schaaf, 2009). No faunal remains or organic tools have been recovered from this component (Schaaf, 2009). Because the earliest occupation at Mink Island has not been radiocarbon dated, Paleoarctic tradition designations are inferred based on the presence of diagnostic artifacts (Schaaf, 2009).

The Paleoarctic tradition is also found at the Ugashik Narrows site, which is between the Upper and Lower Ugashik lakes on the Bering Sea slope (Dumond, 2005; Henn, 1978). The Paleoarctic tradition materials from the Ugashik Narrows site belong to the Ugashik Narrows phase, which dates between 9000 and 7500 BP (Dumond, 2005). Wedge-shaped cores, microblades, scrapers, and large stone knives have been recovered from the site. No bone tools or faunal remains have been encountered (Dumond, 2005). A few concentrations of charcoal have been excavated from the Ugashik Narrows site, which indicates the presence of campfires. However, no tents or other shelters have been uncovered (Dumond, 2005).

The Paleoarctic tradition is also found at the Graveyard Point site near the mouth of the Kvichak River on the Bering Sea slope (Dumond, 2005). The Paleoarctic materials from the Graveyard Point site belong to the Koggiung phase, which dates to ca. 8000 BP (Dumond, 2005). Characteristic stone artifacts include wedge-shaped cores, associated microblades, and a few knife-like artifacts. The Koggiung phase microblades and associated cores were on average larger than those from the preceding Ugashik Narrows phase (Dumond, 2005). No organic materials that date to this phase have been recovered (Dumond, 2005). Artifact concentrations at the Graveyard Point site cluster around a campfire; although it was impossible to determine if some sort of tent or other habitation form was present (Dumond, 2005).

Ocean Bay tradition

Ocean Bay is a maritime-hunting adapted tradition that dates between 7500 and 2800 BP (Clark, 1997; Clark, 1977; Dumond, 1981; Fitzhugh, 1996; Tennessen, 2009; Workman, 1969). The Ocean Bay tradition is found along the Shelikof Strait coast (Takli Alder and Takli Birch), the Bering Sea slope (Brooks River Strand), and the Kodiak Archipelago (Ocean Bay I and II) (Clark, 1997; Dumond, 1981; Fitzhugh, 1996) (Figure 4.1). The Ocean Bay tradition is divided into early (7500-4500 BP) and late (4500-2800 BP) stages based largely on the presence of a ground stone industry (Clark, 1977).

The Ocean Bay tradition likely developed from the early Paleoarctic tradition (Clark, 2001a; Dumond, 1987a; Fitzhugh, 2001, 2003; Steffian *et al.*, 2002) and individuals likely migrated into the region fully adapted to the maritime environment (Fitzhugh, 1996). Ocean

Bay sites tend to be found in areas adjacent to sea mammal haul-outs, rookeries, near nearshore marine habitats, and salmon streams (Fitzhugh, 2002; Kopperl, 2003). The presence of composite fishhooks, bone harpoon parts, and near-shore marine fauna (e.g. marine mammals, birds, shellfish, and fishes) lends credence to the suggestion that the people of the Ocean Bay tradition were maritime-focused (Hausler-Knecht, 1993).

The early stage is associated with the Ocean Bay I (7500-4500 BP) and the Takli Alder (6000-4500 BP) phases. The artifact assemblages connected with the early stage are composed of chipped stone projectile points, knives, and microblades (inserts for slotted bone points) (Fitzhugh, 2002, 2003; Steffian *et al.*, 2002). The late stage is linked with Ocean Bay II (4500-3500 BP), Takli Birch (4500-2800 BP), and the Brooks River Strand phases (4500-3900 BP) (Clark, 1979). The late stage is marked by the large-scale adoption of a ground slate industry. Large, long and narrow, parallel-sided bayonet-like ground points are the most distinctive tool type (Clark, 1979, 2001a; Clark, 1977; Fitzhugh, 1996). Stone vessels (apparently lamps) are associated with the Ocean Bay tradition, as are a few microblades, although they are too few to indicate a microblade industry (Dumond, 1987a).

The first appearance of semi-subterranean houses and substantial tent rings occurs during the Ocean Bay tradition (Hausler-Knecht, 1993; Schaaf, 2009). Ocean Bay sites typically contain thin red ochre-stained occupation surfaces, lack substantial shell midden deposits, and lack evidence of technology aimed at mass harvesting salmon (e.g. weirs and notched stones) (Kopperl, 2003). Fish were captured using hook and line technology during Ocean Bay times (Fitzhugh, 1996; Kopperl, 2003).

Northern Archaic tradition

The Northern Archaic tradition is found on the Bering Sea slope and dates between 7000 and 3800 BP (Anderson, 1984, 1988; Workman, 1998b). The Northern Archaic tradition represents a combination of forest-dwelling American Indians, who arrived from the south, and remnant Paleoarctic tradition descendants who developed *in situ* (Dumond, 1987a). Because Northern Archaic tradition sites are often in the boreal forest, there appears to be continuation in the late prehistoric material culture. Athapaskan-speakers are thought to have developed

from the Northern Archaic tradition (Anderson, 1984, 1988; Workman, 1998b). There are no parallels between Northern Archaic tradition assemblages and assemblages from Asia, although parallels may be made with parts of southern Canada and the continental United States by as early as 8000 BP. In general, these Northern Archaic tradition assemblages are associated with big game hunting (often bison) and fishing (Ackerman, 2004; Anderson, 1988; Dumond, 1984a, 1987a).

Asymmetrical projectile points with deep, wide, side-notches; large unifacially flaked knives; flaked side and endscrapers; notched pebbles; and heavy cobble tools characterize the Northern Archaic tradition artifact assemblage (Ackerman, 2004; Anderson, 1988; Campbell, 1961; Workman, 1998b). However, over time, projectile points become shorter, notched pebbles appear, and some slate objects appear (Dumond, 1987a). Additionally, some Northern Archaic sites contain microblades and blades; however, their presence is not typical (Workman, 1998b).

Northern Archaic tradition assemblages have been recovered from the Bering Sea slope within the study area and are associated with Ugashik Knolls (7000-4500 BP), Graveyard (7000-4500 BP), and Brooks River Beachridge (4000-3800 BP) phases (Dumond, 2005). Stone tools associated with the Ugashik Knolls and Graveyard Point phases include crudely made stone points (atlatl darts), scraping tools, and notched pebbles (for fishing). Characteristic Brooks River Beachridge stone tools include leaf-shaped flaked stone points and small, flaked-stone scraping tools. Northern Archaic habitation types are comprised of small campsites, which often contain large numbers of smashed mammal bone (probably caribou limb bones) (Dumond, 2005). The Brooks River Beachridge phase occupants were most likely the *in-situ* descendants of the earlier Ugashik Knoll and Graveyard phases (Dumond, 2005). No Northern Archaic tradition assemblages have been recovered on the Shelikof Strait coast of the Alaska Peninsula or the Kodiak Archipelago.

Arctic Small Tool tradition

The Arctic Small Tool tradition is a far-reaching cultural tradition that has been found from the Bering Sea slope across northern Alaska and Canada to the narrow coastal strip of

Greenland (Dumond, 1987a). The Arctic Small Tool tradition is likely descended from the Siberian aspect of the Paleoarctic tradition whose occupants exploited the tundra environment in search of caribou and musk oxen (although salmon and seal were also consumed when available) (Dumond, 1987a). Alaskan Arctic Small Tool tradition sites date between 4700 and 2500 BP (Dumond, 1987a). Associated stone tools tend to be small and consist of bipointed endblades and sideblades, small burinated bifaces, microblades, large knife-like bifaces, several types of scrapers, small adze blades with polished bits, and polished bit burin-like implements (Dumond, 1987a, 2001; Giddings, 1964; Maxwell, 1985). No organic artifacts have been recovered from Alaskan sites because of lack of preservation. Arctic Small Tool tradition assemblages from the Bering Sea slope have fewer burins and microblades than other Arctic Small Tool tradition sites (Dumond, 1987a).

Arctic Small Tool tradition sites have been uncovered at terrace sites along the Brooks River and at Naknek Lake on the Bering Sea Slope (Dumond, 1971, 1981, 2005). These Arctic Small Tool tradition sites belong to the Brooks River Gravels phase, which dates between 3900 and 3100 BP (Dumond, 2005). Numerous Arctic Small Tool tradition houses (over 100) are associated with several terrace sites along the Brooks River. The associated semi-subterranean houses average 4x4 m. Central fireplaces with or without a rock outline are common as are sloping house entranceways, which suggests that these habitations are probably winter dwellings (Dumond, 1971). Other, more informal campsites, line the banks of the Brooks River. Crushed mammal and fish bone has been found in association with a few campfires along the river (Dumond, 1971).

The Brooks River Gravels phase toolkit is different from that of earlier phases because flaked bipoints were probably used to tip arrows rather than spears or atlatls. Additionally, the well-made and delicate scraping tools, small stone adzes, and burins are different from other tools from the Alaska Peninsula (Dumond, 1987a, 2005). Around 3100 BP, the Brooks River Gravels phase and the Arctic Small Tool tradition abruptly ended on the Alaska Peninsula. It is believed that in the Naknek region, a volcanic eruption (volcanic ash F from the Aniakchak Volcano) caused the subsistence base (e.g. caribou and salmon) to collapse (Dumond, 2000; Finney *et al.*, 2002; Giddings and Anderson, 1986; Riehle *et al.*, 2000; VanderHoek, 2009).

Arctic Small Tool tradition artifacts have been found at a few sites in the Kodiak Archipelago and the Shelikof Strait coast but here they are mixed with artifacts from coastal-adapted people (Clark, 1997; Dumond, 2005; Knecht *et al.*, 2001). A more clearly related Arctic Small Tool tradition site was found in Kachemak Bay, which represents the southernmost incursion of Arctic Small Tool tradition people (Clark, 1997; Dumond, 2005; Knecht *et al.*, 2001; Workman, 1998a).

Kachemak tradition

Frederica de Laguna first encountered cultural materials associated with the Kachemak tradition in Kachemak Bay in outer Cook Inlet in the 1930s (de Laguna, 1934). Subsequent research revealed that the nucleus of the tradition resided to the west in the Kodiak Archipelago (Clark, 1992b, 1997, 2001b). Kachemak tradition cultural materials have also been recovered from Prince William Sound (Clark, 2001b; Yarborough and Yarborough, 1998), the upper Kenai Peninsula (Reger, 1998), and the Shelikof Strait coast (Clark, 1992b). The Kachemak tradition is absent from the Bering Sea slope (Dumond, 2005).

The development of the Kachemak tradition coincides with the height of the Neoglacial period (3500-2500 BP) (Crockford and Frederick, 2007). During the Neoglacial period, local conditions became colder and wetter, resulting in more frequent and intense storms (Calkin *et al.*, 2001). The increased storms altered resource distributions and made it more difficult for human occupants to access the maritime resources that were available (Fitzhugh, 2002). In response to the local resource depression, the occupants of the Kachemak tradition broadened their diets to include larger numbers of fish and shellfish (Clark, 1984; Fitzhugh, 1996). The broadening of their diet required technological innovations, which is visible in the archaeological record as an increase in the number of notched and grooved stones (fishing weights) and ulus (often used to cut fish) (Clark, 1997). While fishing tools increased in number during the Kachemak tradition, hunting tools decreased in number, and slate projectile points decreased in size (Fitzhugh, 2001, 2002). During the Kachemak tradition, sedentism increased, and large villages, which were likely occupied for most of the year and inhabited for many years, began to

appear (Fitzhugh, 1996). Artistic expression, warfare, and violence also increased, especially during the Late phase (Clark, 1997; Fitzhugh, 1996; Moss and Erlandson, 1992).

The Kachemak tradition is separated into Early (Old Kiavak phase on Kodiak Island) and Late phases (Three Saints Bay phase on Kodiak Island) (Clark, 1997). The Early Kachemak phase dates between 4000/3500 and 2200 BP and the Late Kachemak phase dates between 2200 and 800/700 BP (Clark, 1997; Fitzhugh, 1996). Artifacts associated with the Late phase are more abundant and diverse than those associated with the Early phase (Clark, 1992b, 1997).

The Early/Old Kiavak phase is found at the Old Kiavak site, the Monaashka Bay site, the Crag Point site, and at Uganik Bay on Kodiak Island (Clark, 1966, 1970, 1974a). The Early phase materials are separated from the Ocean Bay II phase materials by a temporal hiatus of several hundred years. House forms are unknown from Early phase times, although clay lined basins and slab-lined hearths were discovered from the Old Kiavak site (indicative of a house structure). Diagnostic Early Kachemak phase artifacts are limited to notched stones (probably used as fishing weights), necked grooved stones (plummet style, probably also used as fishing weights), toggling harpoon heads, and ground slate tools with holes drilled into them for handle attachment (Clark, 1992b, 1997). The faunal assemblage largely consists of harbor seal, although red fox and a few other taxa have been recovered (Clark, 1974c). At an Early phase site on Uganik Island, a thick band of well-preserved fish bones was found associated with a few mammal bones, which indicates a dependence on fishing (Clark, n.d.).

The Late/Three Saints Bay phase components have been found at Three Saints Bay, Crag Point, and the Uyak sites on Kodiak Island, and at the Afognak Aleut Town Site, the Salmon Bend Site, and the Tsunami house on Afognak Island (Clark, 1970, 1997, n.d.; Heizer, 1956). The Late phase represents the cultural climax on the Kodiak Archipelago, and is characterized by an increase in personal adornment, burial ceremonialism, and symmetrical workmanship connected to ground slate and organic industries (Clark, 1975). The artifact assemblage consists of a number of bone implements including awls, whalebone wedges, needles, harpoon heads, arrowheads, leister prongs, fishhooks, and fish effigy lures (Clark, n.d.). Stone artifacts include adze bits, whetstones, abraders, cobble spalls, small notched pebbles (net sinkers), decorated stone lamps, flaked (rare) and ground stone points (lanceolate, leaf shaped, and stemmed) (Clark, 1997, n.d.). Ornaments include human and animal figurines, doll parts, pins, combs,

buckles, miniature harpoons, beads (made of jet, amber, a red stone, ivory, and shell), rings (ears, nasal septum), labrets (coal, ivory, and possibly wood), and incised slate pebbles (Clark, 1997, n.d.; Steffian 1992b). The small notched pebbles and the decorated stone lamps are phase diagnostic artifacts (Clark, 1970). The faunal assemblage associated with this phase consists mostly of harbor seal and red fox; sea otter were surprisingly rare (Clark, 1970). Associated houses have been recovered at the Uyak site, where Heizer (1956) found single-room rectangular houses, and a circular house that was 28 feet in diameter. A burned plank structure was uncovered at Crag Point, and other features such as rectangular slab hearths and small clay-lined basins have been uncovered at the Tsunami House site (Clark, 1970, n.d.).

The extent to which the Kachemak tradition peoples inhabited the Shelikof Strait coast of the Alaska Peninsula remains unclear. Artifacts recovered from the Shelikof Strait coast demonstrate clear connections to the preceding Takli Birch phase of the Ocean Bay tradition as well as to the Norton sub-tradition of the Bering Sea slope (Clark, 1992b; Dumond 1971). Notched stones, grooved stones, ulus, toggling harpoons, and labrets are indistinguishable between the Norton sub-tradition and the Kachemak tradition (Clark, 1992b). Dumond (1971) suggests that the Norton sub-tradition peoples intermingled with Kachemak tradition peoples along the Shelikof Strait coast. More archaeological fieldwork is needed to explore the range of human habitation along the Shelikof Strait coast during this period.

Norton tradition

The Norton tradition is found throughout western Alaska from Cook Inlet and the Upper Alaska Peninsula to Point Barrow. The Norton tradition is divided into three sub-traditions: Iputak, Choris, and Norton. The Norton sub-tradition is found on the Bering Sea slope and Cook Inlet, and is relevant to this discussion. The Norton sub-tradition dates between 2500 and 1000 BP (Dumond, 1987a, 2001; Crowell and Mann, 1998).

Occupants of the Norton sub-tradition hunted sea mammals and caribou and fished for salmon (Dumond, 1987a, 2000; Workman, 1982). Norton sub-tradition artifact assemblages consist of a variety of flaked-stone implements, scraped and polished slate (projectile points and ulus), pecked oil lamps, notched stones (net weights), open socket harpoons, and the earliest

pottery in Alaska (Dumond, 2000; Workman, 1982). Norton sub-tradition artifacts are similar to those from the preceding Arctic Small Tool tradition as well as to those from contemporary Aleutian tradition assemblages from the lower Alaska Peninsula and the Aleutian Islands. On the Bering Sea slope, large Norton sub-tradition sites are clustered along the major salmon streams (Ugashik, Naknek, Kvichak, Wood, and the Nushagak) (Dumond, 1981, 1987a; Henn, 1978). Notched stones are common and suggest that salmon were an important component of the diet. In sites that favor bone preservation, caribou antler is numerous (Dumond, 1987a).

Along the Bering Sea slope, the Norton sub-tradition is represented by the Smelt Creek (2200-1900 BP), the Brooks River Weir (1900-1400 BP), and the Brooks River Falls phases (1400-1000 BP) (Dumond, 1971, 2005). The Smelt Creek phase represents the arrival of the Norton sub-tradition people into the region from northern locations (Dumond, 1977, 2000; Giddings, 1964; Larsen and Rainey, 1948; Shaw and Holmes, 1982). A substantial (ca.1000-year) gap exists between the end of the Arctic Small Tool tradition occupation and the beginning of the Norton sub-tradition occupation (Dumond, 2005). This occupational hiatus coincides with a volcanic eruption, which may have had a substantial impact on the flora and fauna of the region (Riehle *et al.*, 2000; VanderHoek, 2009).

Differences in artifact assemblages among the three Norton sub-tradition phases along the Bering Sea slope (Smelt Creek, Brooks River Weir, and Brooks River Falls) are largely stylistic. Each of the Norton sub-tradition phases contain small, stemmed points; side blades; drill-like perforators; small, flaked adze blades; tanged slate ulus; and formed stone vessels (Dumond, 1971). The Smelt Creek and Brooks River Falls phases also contain notched pebble sinkers and top hat-shaped coal labrets (Dumond, 1971). Organic artifacts are absent from Norton sub-tradition sites along the Bering Sea slope (Dumond, 1971). Characteristic pottery is fiber tempered, and ranges from thin (Smelt Creek phase) to thick (Brooks River Weir and Brooks River Falls phases) (Dumond, 1969). Vessels differ in shape and include vase-like with a restricted mouth (Smelt Creek phase), barrel-shaped (Brooks River Weir phase), and cylindrical-shaped (Brooks River Weir and Brooks River Falls phases) (Dumond, 1969). Norton sub-tradition pottery tends to be undecorated or decorated with small to large squares or diamond shapes (Dumond, 1971). Norton-sub tradition house forms along the Bering Sea slope tend to be semi-permanent structures that possess a central hearth, a sunken entry, and are oblong (Smelt

Creek phase) to square (Brooks River Weir phase) in shape. House sizes vary from 3.5 x 5 m to 15 x 15 m (Dumond, 1971, 2005).

During the Brooks River Weir phase times (1900-1400 BP), there is evidence suggesting communication across the Alaska Peninsula with contemporary Shelikof Strait coastal occupants (Clark, 1977; Dumond, 2005). Along the Shelikof Strait coast, the Norton sub-tradition is represented by the Takli Cottonwood (1800-1500 BP), and the Kukak Beach (1500-1000 BP) phases (Clark, 1977; Dumond, 1971, 1981, 1998). The Shelikof Strait coast phases are closely related to those of the Naknek and Ugashik drainages (Clark, 1977; Dumond, 1981, 1998). Characteristic Takli Cottonwood and Kukak Beach artifacts include small, finely flaked projectile points with rounded to sharp shoulders; small bipoints; small, slender-pointed knives; drills; flaked adzes with ground bits; ground slate stemmed projectile blades; drilled and undrilled slate ulus; notched pebble sinkers; and formed slate vessels (lamps) (Dumond, 1971). The Kukak Beach phase also contains mauls, decorated stone vessels (lamps), and top hat-shaped coal labrets (Clark, 1977; Dumond, 1981, 1998). Characteristic Takli Cottonwood pottery is thin to thick, out-flaring cylinder-shaped, undecorated, and fiber-tempered (Dumond, 1971). Kukak Beach pottery is fiber-tempered and undecorated (Dumond, 1971). Organic artifacts are absent from Takli Cottonwood phase assemblages. Organics have been recovered from Kukak Beach assemblages and include bone toggling harpoon heads, and unilaterally and bilaterally barbed dart heads (Dumond, 1971). House structures are also common along the Shelikof Strait coast and tend to be square to rectangular in shape. House sizes increase over time, ranging from 5 x 5 m (Takli Cottonwood phase) to 7 x 6.5 m (Kukak Beach phase) (Dumond, 1971). The Norton-sub tradition is absent from the Kodiak Archipelago, which is represented by the contemporary and similar Kachemak tradition (Clark, 1977).

Thule tradition

The Thule tradition is a widespread maritime-hunting-focused tradition that ranged from Cook Inlet, Kodiak Island, the Aleutian Islands, both coasts of the Alaska Peninsula, Northern Alaska, and Northern Canada to Greenland (Dumond, 1984b, 1987a; Harritt, 1988; Henn, 1978; Workman, 1980). Associated Thule tradition phases include Brooks River Camp

(Bering Sea slope), Brooks River Bluffs (Bering Sea slope), Pavik (Bering Sea slope), Kukak Mound (Shelikof Strait coast), and Koniag (Kodiak Archipelago) (Clark, 1974a, 1974c; Dumond, 2005). The Thule tradition is found within the study area between 900 BP and A.D. 1870 (Dumond, 1971). By 900 BP, the Thule tradition appeared on the Bering Sea slope, the Shelikof Strait coast, and the Kodiak Archipelago where Thule tradition peoples mixed with the local residents of the late Norton sub-tradition and Kachemak tradition (Clark, 1974a; Dumond, 1971).

Thule tradition peoples brought their gravel-tempered pottery, polished slate implements, and houses with sunken entrances into the region. Thule influence also resulted in an increased use of bone toggling harpoon heads as compared to non-toggling barbed harpoon heads (Dumond, 1987a). Elaborately decorated ivory and bone implements used to obtain birds, fish (marine and riverine), and sea mammals became more numerous during the Thule tradition (Dumond, 1971). Along with the changes in material culture, the Thule tradition people likely brought a new form of Western Eskimo speech, which became the dominant language in the region (Dumond, 1987a). Increases in population and a rise in warfare and social inequality are also associated with the Thule tradition (Clark, 1977; Dumond, 1981, 1994a, 1994b; Erlandson *et al.*, 1992; Fitzhugh, 1996; Henn, 1978; Knecht, 1995).

Thule tradition settlement patterns demonstrate an increase in the use of riverine environments, which is indicated by an increase in the number of villages along major streams. Thule tradition houses tended to be larger and more complex than houses from the preceding traditions (e.g. Kachemak and Norton) (Clark, 1984). Many Thule tradition houses had sunken entrances and multiple side rooms, some of which contained piles of fire-cracked rocks, which have been interpreted as the remains of sweat baths (Clark, 1984). Storage features (e.g. clay lined pits, slate boxes, and wooden boxes) are also numerous and may be found in interior and exterior locations within Thule tradition assemblages (Clark, 1984).

Along the Bering Sea slope the Thule tradition is represented by the Brooks River Camp (1000-700 BP), Brooks River Bluffs (700-200 BP) and the Pavik (A.D. 1800-1870) phases (Dumond, 1971, 2005). Characteristic stone artifacts associated with the Brooks River Camp phase include slate adze blades with ground bits, and flaked slate bifaces, barbed or shouldered ground slate projectile insert blades, ground slate knife and dart blades, ground slate ulus, large sandstone grinding slabs, whetstones, sandstone saws, formed stone lamps, and wide coal

labrets (Dumond, 1971). Characteristic pottery is thick, gravel-tempered, globular jar-shaped, and plain or concentric circle stamp impressed. Saucer-shaped lamps of unbaked clay are also present and replace the oil burning stone lamps of the Brooks River period (Dumond, 1971, 2005). Characteristic bone artifacts include large whalebone wedges and clubs, unilaterally barbed arrowheads with a tapered pointed base, and unilaterally barbed dart heads with wedge-shaped tangs and a line hole (Dumond, 1971). Houses are roughly square in plan and range from 3x4 m to 4x5 m in size. Sunken entryways are common as are low benches within the houses. Central wood fires provided warmth; these houses would have been suitable for winter occupation. Other, casual campsites are also present during this phase as are clay-lined pits (Dumond, 1971). Large numbers of caribou and salmon bones and fewer other land mammals (beaver, porcupine, and wolves/dogs), birds (duck, goose, eagle, and gull) and the occasional sea mammal (harbor seal) bones have also been associated with the Brooks River Camp phase (Dumond, 1971).

Characteristic Brooks River Bluffs phase stone artifacts include tanged and tangless ground slate ulus, ground slate projectile insert blades, slate adze blades, splitting adzes, sandstone saws, pecked stone vessels (lamps), and wide coal labrets (Dumond, 1971). Characteristic pottery is thick or thin, gravel tempered, plain or with a molded external ridge and is either globular jar- to flower pot-shaped (Dumond, 1971). Characteristic bone artifacts and associated faunal remains are similar to the Brooks River Camp phase (Dumond, 1971, 2005). The Brooks River Bluffs phase was once thought to be a continuation of the preceding Brooks River Camp phase (See Davis, 1954; Dumond, 1971) with the three phases of the Naknek period linked in an unbroken evolutionary progression. More recent research (see Dumond, 1994b, 2003) indicates that different people occupied the Naknek River drainage during the two phases. The material culture and house types of the Brooks River Bluffs phase more closely resembled those of the contemporary Koniag phase from the Kodiak Archipelago (e.g. ulus with bored holes for handle attachment, large double-edged lance blades or knives, thinner, more flat bottomed pottery shape, pecked stone oil lamps rather than saucer-shaped clay lamps, and multi-roomed houses) (Dumond, 1994b, 2003). The presence of a thick volcanic ash layer (ash C) between the Brooks River Camp phase and the Brooks River Bluffs phase also lends credence to this interpretation. After the volcanic eruption (most likely from the Aniakchak Volcano), the

Brooks River Camp phase occupants left the region (Dumond, 2003). Radiocarbon evidence suggests that about 50 years passed before the Naknek River region was reoccupied by people belonging to the Brooks River Bluffs phase who were directly affiliated with Kodiak Island (Dumond, 1981, 2003, 2005; Harritt, 1988; VanderHoek, 2009).

The Pavik phase is found at the Paugvik site along the Naknek River on the Bering Sea slope (Dumond, 1971, 2005). At the beginning of the Pavik phase (A.D. 1800), warfare pushed a group of people (Aglegmiut, now known as Aglurmiut) from their homeland in the Kuskokwim River region. These Aglurmiut then immigrated to the Bristol Bay region and displaced the coastal peninsular occupants who were descendants of the Brooks River Bluffs phase (Dumond, 2005). The coastal occupants then moved from the Bristol Bay region to interior regions of the Alaska Peninsula and settled at Savonoski and Ugashik (Dumond, 2005). Therefore, the people with whom the Russians encountered sometime around A.D. 1791 were newcomers to the region, the Aglurmiut, who spoke Central Yupik (Dumond, 2005; Solovjova and Vovnyanko, 2002). Characteristic stone artifacts from Paugvik consist primarily of triangular faceted ground slate projectile insert blades. Typical pottery is flowerpot-shaped, thin, plain, and gravel tempered. Characteristic bone artifacts include unilaterally barbed dart and arrowheads, bilaterally barbed dart heads, undecorated toggling harpoon heads, sled shoes, and spoons with decorated handles. Because of the short time-depth coupled with exceptional preservation conditions, wooden objects (skin stretchers, vessels, bow fragments, and small carvings that once adorned masks), grass matting, and leather were also recovered from the Pauvik site (Dumond, 2005). European manufactured items are also numerous and include steel knives and axes, iron projectile blades, window glass, chinaware, and glass trade beads (Dumond, 1971). House forms change drastically during the Pavik phase and are typical of the Russian and early American period. Faunal remains consist of caribou, moose, small land mammals, small whales, walrus, and salmon (Dumond, 1971).

At about 900 BP, there is evidence that some of the Brooks River Camp phase (maritime focused Thule tradition) people migrated across the Aleutian Range of the Alaska Peninsula to the Shelikof Strait coast (Kukak Mound phase) (Clark, 1977; Dumond, 2005). Characteristic stone artifacts associated with the Kukak Mound phase include small stemmed projectile points; flaked slate bifaces; adze blades with ground bits; ground slate dart and knife blades; ground

slate projectile insert blades; small, tapering, ground slate knives; drilled and un-drilled ground slate ulus; formed stone lamps; and notched pebble sinkers (Clark, 1977; Dumond, 1971). Typical pottery is gravel-tempered and the shape changes from cylindrical to a globular-jar form (Dumond, 1971). Characteristic bone artifacts include leister parts, unilaterally barbed dart heads with a wedge-shaped tang and line hole, and unilaterally barbed dart heads with conical tangs (Dumond, 1971). Houses tended to be square in plan, have a cold trap entrance, and were around 5x5 m in size. Sparse faunal remains indicate that sea mammal hunting and riverine fishing remained dominant, although land mammals were also procured (Clark, 1977).

The Koniag phase of the Thule tradition dates between 900 BP and A.D. 1763, and is found within the Kodiak Archipelago (Clark, 1974a, 1974c; Heizer, 1956). As the Norton sub-tradition is absent from the Kodiak Archipelago, the Koniag phase follows the Late Kachemak (Three Saints Bay) phase (Clark, 1974a). The main differences between the Late Kachemak and the Koniag phases are stylistic, with Koniag phase artifacts being less elaborately made than were their predecessors. There are fewer styles of stone and bone projectile points (more specialized), barbing is uncommon on all but the largest slate blades, and there are fewer ornaments, art objects, and decorated items. More stone adzes, grooved splitting adzes, and large bone wedges are associated with the Koniag phase, indicating an increased importance placed on woodworking (Clark, 1984). Small-notched stones associated with the Late Kachemak disappear during Koniag phase times as do the exotic practices associated with burial ceremonialism. Burned rubble indicating a vapor sweat bath, plain gravel-tempered ceramics, incised slate figurines, and large notched cobbles are also associated with the Koniag phase (Clark, 1975). Some Koniag phase sites lack pottery early in the second millennium A.D., which may indicate that two social spheres may be present during this period (Clark, 1974c). Human burials were often located in the living area in a flexed position, but there is evidence for cairn burial, and ethnographic resources indicate mummification and cave burial. The subsistence practices are similar to those of the Late Kachemak phase except that red foxes are less abundant and fur seal becomes more common in the early contact period (Clark, 1974c, 1975).

Regional Connections and Discussion

Paleoarctic tradition cultures are found in widespread locations including the Aleutian Islands, the Alaska Peninsula, interior Alaska, Cook Inlet, Southeast Alaska, and British Columbia (Ackerman *et al.*, 1979, 1985; Aigner *et al.*, 1976; Anderson, 1970, 1972, 1984; Davis *et al.*, 1981; Davis, 1989; Holmes *et al.*, 1989; Powers and Hoffecker, 1989; Reger, 1977, 1981). The use of wedge-shaped cores and microblades link these earliest occupants (Dumond, 1987a). Diagnostic shouldered and contracting stem projectile points of the Ugashik Knoll phase of the Bering Sea Slope coast are suggestive of maritime-hunting adaptation (Clark, 1975; Henn, 1978). Similar stemmed points are found from British Columbia to the south (Clark, 1974b), and later in the Takli Alder and Ocean Bay I phases to the east (Clark, 1975).

Ocean Bay tradition peoples (Takli Alder, Takli Birch, Ocean Bay I, Ocean Bay II, and Brooks River Strand phases) represent a maritime-hunting adaptation that most likely developed from the earlier Paleoarctic tradition (Clark, 2001a; Dumond, 1987a; Fitzhugh, 2001, 2003; Steffian *et al.*, 2002). There is a close relationship between the Takli Alder and the Takli Birch phases differing mainly in the relative frequencies of artifact types and the presence of ground slate in the Takli Birch phase (Clark, 1977). Polished slate similar to the Takli Birch phase is present in the Ocean Bay II assemblage from Kodiak Island (Clark, 1966) and the Brooks River Strand phase of the Naknek drainage by 4500 BP (Dumond, 1971). Dumond concludes that the use of polished slate began on the Shelikof Strait coast of the Alaska Peninsula before 4500 BP. The polished slate industry was then brought across the Aleutian Range to the Bering Sea slope of the Alaska Peninsula by peoples in search of caribou. The presence of oil-burning lamps in the Brooks River Strand phase corroborates this suggestion, as they are markers of a coastal sea mammal hunting-adaptation (Dumond, 2005).

A disruption in regional culture history sequence roughly coincides with the height of the Neoglacial period between the Takli Birch and the Takli Cottonwood phases (Crowell *et al.*, 2003). The Takli Cottonwood phase is only visible at a few small sites, which makes it difficult to evaluate. Increases in fishing-related artifacts (net sinkers, grooved stones, ulus, etc.) suggest a possible link with Kachemak tradition peoples (Clark, 1992b). Pottery and small-flaked points associated with the Takli Cottonwood phase possibly indicate a link with northern peoples of the

Arctic Small Tool tradition. The use of pottery also links the Takli Cottonwood phase with the subsequent Kukak Beach phase. The increasing frequency of small projectile points is also indicative of increasing northern influence during the Kukak Beach phase. This shift in ceramic type (from fiber-to gravel-tempered) coupled with the almost complete disappearance of flaked stone projectile points make the Kukak Mound phase distinct from the Kukak Beach phase. There is another substantial hiatus in the archaeological record between the Kukak Beach phase and historic times (Clark, 1977).

Throughout all of the cultural phases on the Shelikof Strait coast (including Mink Island); sea mammals dominate the faunal remains over land mammals. A coastal focus may be expected because the steep mountains bordering the coast prohibited easy access to caribou (Dumond, 1987a). Although there is evidence that on a seasonal basis, the people of the Shelikof Strait coast traveled across the mountains to procure resources (most notably caribou) on the Bering Sea Slope. Seasonal migration to hunting grounds occurred until 3900 BP when Arctic Small Tool tradition peoples moved into the region (Dumond, 1971).

House forms from the Takli Alder and the Takli Birch phases are large oval or round in plan. Whereas house forms from the Takli Cottonwood, Kukak Beach, and the Kukak Mound phases are rectangular in plan. The "Typical" North Pacific house form with an additional room is rare (Clark, 1977). This may indicate that the house form may be derived from the smaller Arctic Small Tool tradition houses found in the Bering Sea drainage to the north (Dumond, 1971).

Based on the similarity of artifact types and house forms between the Shelikof Strait coast and the Bering Sea slope, it is clear that there are some connections. By the first millennium BP, there are increasing cultural influences emanating from the Bering Sea slope that spread along the Shelikof Strait coast (Clark, 1977). Dumond (1987a) suggests that the Kukak Beach phase (1500 - 1000 BP) is so similar to the Norton sub-tradition of the north that he suggests acculturation of Norton sub-tradition people into the region rather than seasonal incursion of Bering Sea people. At 1000 BP, there appears to be another shift with the increased use of ground stone compared to flaked stone and a shift from fiber-tempered to gravel-tempered pottery (Workman, 1980). Dumond attributes this shift to the penetration of Thule tradition people from the far north (Dumond, 1987a). Therefore, it appears that two pulses,

first by Norton sub-tradition peoples and then by Thule tradition peoples, influenced the peoples of the Shelikof Strait coast (including Mink Island occupants).

Along with the connection to the north, the cultural phases of the Shelikof Strait coast are also related to the cultural phases of the Kodiak Archipelago (Clark, 1975; Clark, 1977). The Takli Alder phase is similar to the Ocean Bay I phase found on Kodiak Island. The main differences are the presence of a degenerate microblade industry, a small amount of ground slate, and stone wedges at the Ocean Bay I phase (AFO 106) site on Kodiak Island and the presence of large polished adzes at the Takli Alder phase sites on the Alaska Peninsula (Clark, 1975; Clark, 1977). The Takli Birch phase and the Ocean Bay II phase are different in a number of important respects (Clark, 1974b, 1975; Clark, 1977). The main differences are that the Takli Birch phase artifact assemblages include ulus and a mixed stone flaking and grinding technology that is absent from Ocean Bay II artifact assemblages. Another divergence is the lack of emphasis on the saw-snap and scrape slate technology characteristic of the Ocean Bay II phase (Clark, 1974b; Clark, 1977; Workman, 1980). Some of these distinctions may be because the Takli Birch phase postdates the Ocean Bay II phase (Clark, 1979).

The Shelikof Strait coast and the Kodiak Archipelago are not easily compared during Kachemak tradition times because there is a hiatus in the archaeological record around 4000 BP on Kodiak Island, and the Takli Cottonwood phase assemblage on the Shelikof Strait coast is small and lacks organics (Workman, 1980). The hiatus occurs between the Ocean Bay II and the earliest phase of the Kachemak tradition (Old Kiavak phase/Early Kachemak phase) within the Kodiak Archipelago (Clark, 1974b, 1979). Some of the general traits of the Kachemak tradition (de Laguna, 1934) are present in the Takli Birch phase, but many of the diagnostic artifacts are absent. For instance, small stone sinkers are present on the Alaska Peninsula while end-grooved weights are absent (Clark, 1977). Dumond suggests that as the ties with the Bering Sea increase, ties with the Kodiak Archipelago decrease (Dumond, 1971). D. Clark (1977:79) suggests that links with the Early Kachemak Phase (Old Kiavak phase) from the Kodiak Archipelago are due to trait diffusion rather than to a genetic connection (Clark, 1975, 1979). However, additional research is needed to explore the range of human occupation on the Shelikof Strait coast during the Kachemak tradition.

G. Clark (1977) notes a similarity between the Kukak Mound phase and the Koniag phase on Kodiak Island. They are so similar that G. Clark (1977) suggests that they fall within a single cultural area at this time. However, the origin of the Koniag phase peoples has been the subject of much analysis (Clark, 1974c). The changes between the Late Kachemak Phase/Three Saints Bay phase and the Koniag phase in the Kodiak Archipelago are significant enough to suggest that outside influences, possibly including the immigration of new peoples, must have occurred. Although there is enough continuity in the artifact assemblage to suggest that a simple population replacement did not occur. Influences from the Bering Sea, Prince William Sound, and the Northwest Coast occurred to varying degrees to create ceramic Koniag phase variants in the southwestern portion of Kodiak Island and non-ceramic Koniag phase variants in the northwestern portion of Kodiak Island (Clark, 1974c). The greatest influence may be from the Bering Sea, as demonstrated by the introduction of the Eskimo language used by Thule peoples, brought to Kodiak Island during Koniag phase times (Dumond, 1987a).

Because the Mink Island site is along the Shelikof Strait coast, the culture history sequence should include Paleoarctic (unnamed phase), Ocean Bay (Takli Alder and Takli Birch), Norton (Takli Cottonwood and Kukak Beach), and Thule (Kukak Mound) tradition components. Influence from the Bering Sea slope should be visible within the archaeological record during the Paleoarctic, Norton, and Thule traditions. Conversely, increasing influence from the Kodiak Archipelago should be visible during the Ocean Bay and Thule traditions. Whether the Kachemak tradition is present at Mink Island remains unclear at this time as it largely corresponds with the occupational hiatus. Northern Archaic and Arctic Small Tool tradition influences should be minimal within the archaeological record at Mink Island.

Mink Island Site (XMK-030)

The Mink Island site context (e.g. excavation strategy, litostratigraphic divisions, radiocarbon dates, and temporal/cultural zonation) is presented in the following sections. Descriptions of associated features and fishing related artifacts (e.g. fishhooks, leisters, fish scalers, floats, notched stones, and grooved stones) are also included. These data help to place the Mink Island site within the regional cultural history sequence.

The Mink Island site is on a small, unnamed island, approximately two kilometers off the northern Alaska Peninsula mainland within the confines of Katmai National Park and Preserve (Figure 4.2). The unnamed island, informally referred to by the NPS Principal Investigator as "Mink Island", is one of several small islands that compose the Takli archipelago, near the mouth of Amalik Bay (Figures 4.3 and 4.4). The sites within Amalik Bay comprise an Archaeological District listed on the National Register of Historic Places as a National Historic Landmark. The Mink Island is the keystone site of primary significance (Jeanne Schaaf, personal communication, 2011). Mink Island is connected to a neighboring island, informally called "Little Takli Island", by a small northwest to southeast trending sand bar (tombolo) that is exposed from mid to low tide levels (Hilton, 2002; Mason *et al.,* 2008). During high tide levels, Mink and Little Takli Islands are separated by 75 (horizontal) meters of water (Hilton, 2002). Rounded cobbles, large boulders, and coarse gravels dominate the intertidal zone on Mink Island, whereas wave-scoured bedrock covered by a deep layer of sand dominates the same zone on Little Takli Island (Hilton, 2002). The bedrock on both islands is comprised mainly of tertiary volcanic rock covered by glacial till; which reaches 20 meters thick on the southern end of Mink Island (Mason *et al.,* 2008).

The Mink Island site is on a small bedrock outcrop above a tidal flat that projects from the northwestern portion of the island (Figure 4.5). The cultural deposits are between 2 and 8 meters above the high tide line and encompass an area of 4400 m^2 (Hilton, 2002). The bedrock outcrop where the Mink Island site resides is connected to Mink Island proper by a tombolo, which provided unrestricted access between the two landforms (Figure 4.4) (Hilton, 2002).

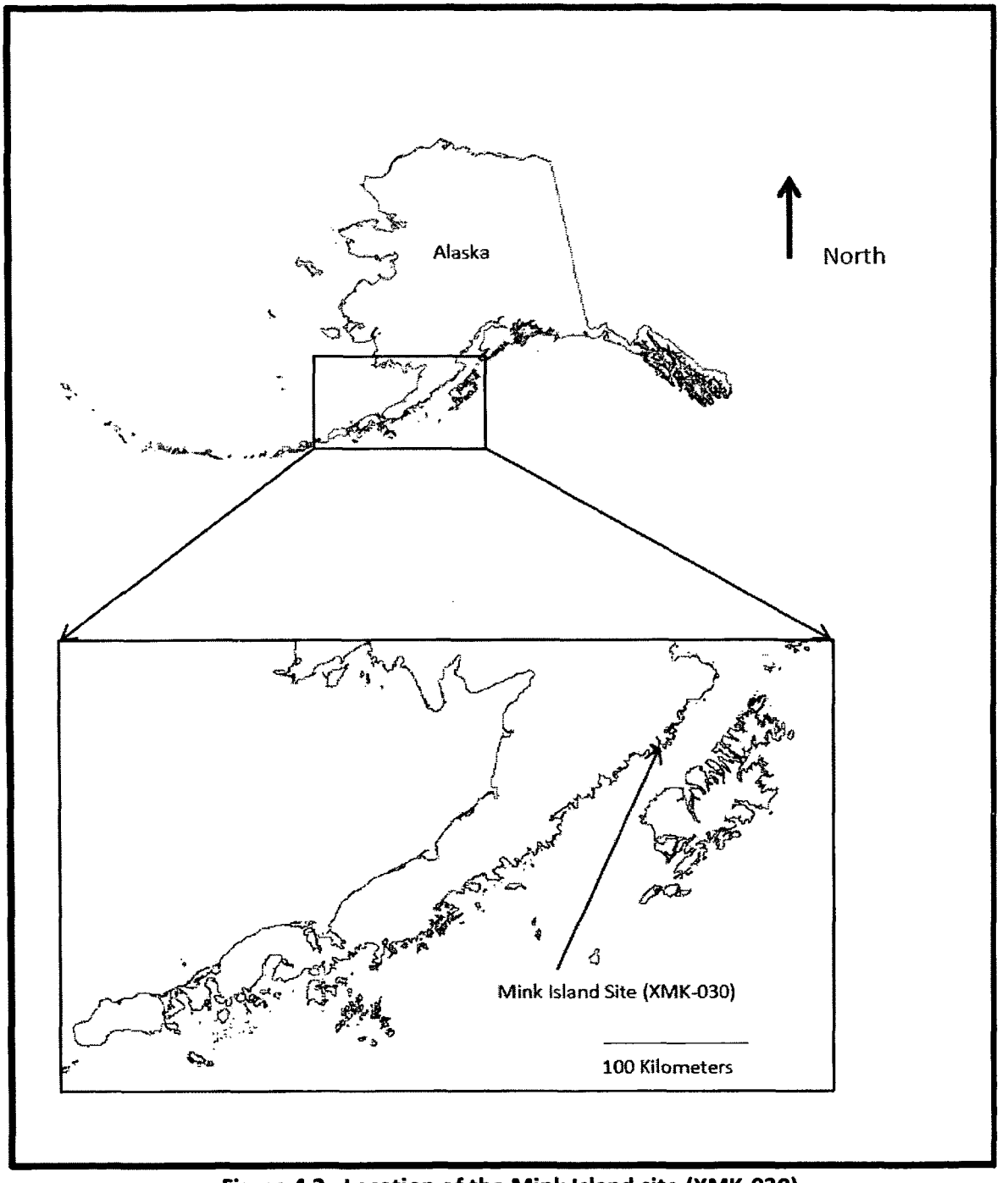


Figure 4.2. Location of the Mink Island site (XMK-030).

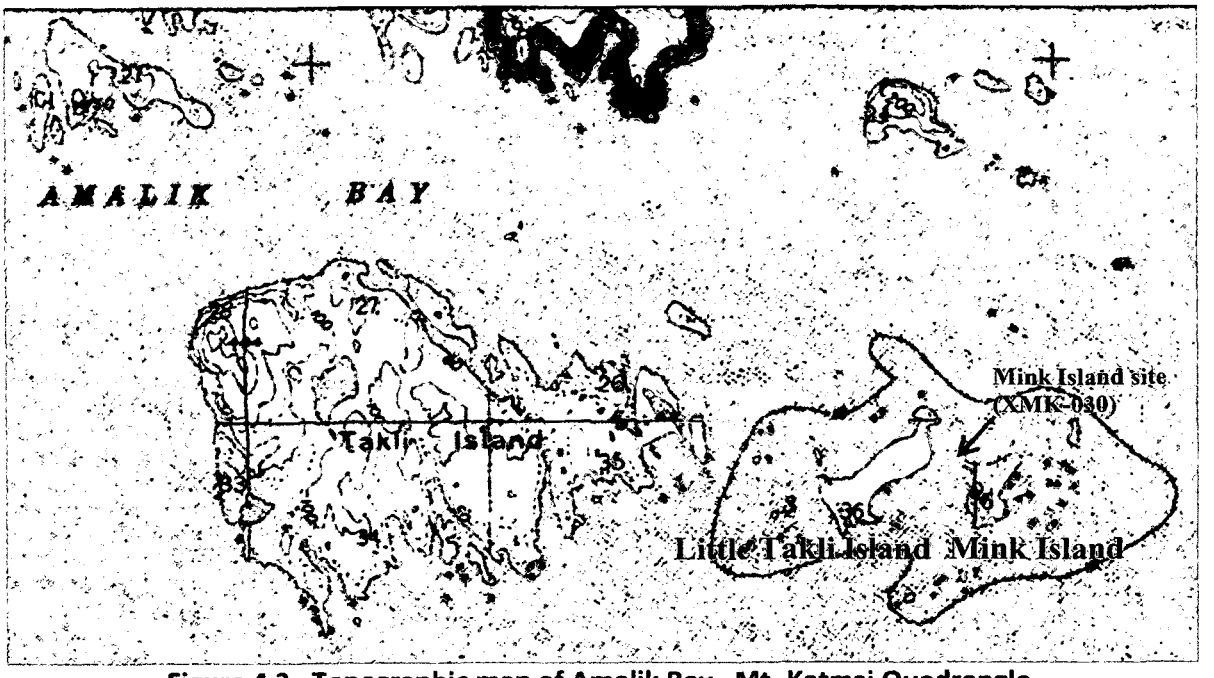


Figure 4.3. Topographic map of Amalik Bay. Mt. Katmai Quadrangle.

Figure 4.4. Photograph of Mink Island and Little Takli Island (in the foreground). Photograph by Jeanne Schaaf, NPS.

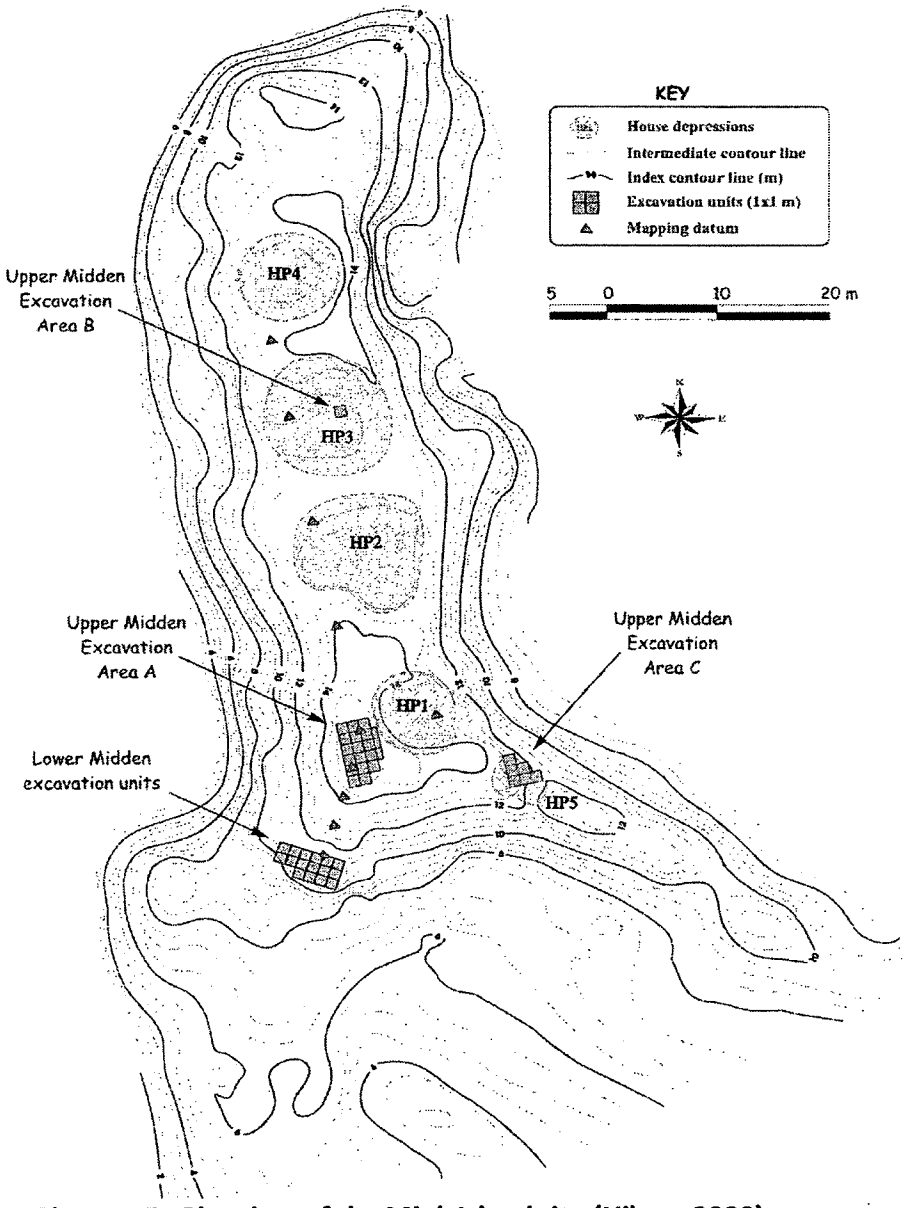


Figure 4.5. Planview of the Mink Island site (Hilton, 2000).

Recent Archaeological Research at Mink Island

Archaeological investigations described here began in 1996 when Jeanne Schaaf (newly appointed Cultural Resource Manager for the Lake Clark, Katmai, and Aniakchak Park Cluster) brought Don Dumond (University of Oregon) to the Mink Island site to assess its significance and evaluate the need for further archaeological investigations. Dumond had worked extensively in the immediate area and the broader Alaska Peninsula region and was able to provide an assessment of the site's significance. Schaaf and Dumond noted artifacts eroding from the site that represented most of the known cultural expressions documented for the area. They determined the Mink Island site would yield information important to understanding Alaska's prehistory and that data recovery excavations should be completed at the portion of the site threated by immediate loss from erosion. Because human remains were eroding at the site, consultation with Katmai Affiliated tribes and other interested Native groups was initiated (Jeanne Schaaf, personal communication, 2011).

From 1997 until 2000, the National Park Service began detailed topographic mapping, vandalism deterrent and monitoring actions, and conducted four seasons (29 weeks) of excavations at the Mink Island site (Hilton, 2002). The excavations were focused on the relatively small portions of the site that were in danger of being lost to erosion. A 2x6 m block at the base of the cultural deposits (Lower Midden) and a 3x5 m block at the top of the cultural deposits (Upper Midden) were excavated (Figure 4.5). The Upper Midden was the source of the human remains, which were collected and removed from *in situ* contexts per the Native American Graves Protection and Repatriation Act (NAGPRA) Memorandum of Understanding (MOU) (Jeanne Schaaf, personal communication, 2011).

The older component, which dates to 5047 - 6590 cal. BP (Jeanne Schaaf, personal communication, 2011), is at the base of the bedrock landform by the Mink Island site and is identified hereafter as the "Lower Midden"(Figure 4. 5) (Hilton, 2002). The more recent component, which dates to 455 - 1915 cal. BP (Hilton, 2002: 135, Table 5.2; Jeanne Schaaf, personal communication, 2011), lies on the crest of the bedrock landform and is identified hereafter as the "Upper Midden" (Figure 4.5). Following the work of others (Hilton, 2002; Schaaf, 2009; Tennessen, 2009) the term "Midden," when capitalized as a proper noun, is used

colloquially to identify the two loci at the Mink Island site and does not explicitly refer to refuse zones.

Excavation Strategy

Upper Midden

Excavation of the Upper Midden was conducted in three separate localities on top of the bedrock landform (Excavation Areas A, B, and C) (Figure 4.5) (Hilton, 2002). This dissertation focuses on fish remains recovered from Excavation Areas A and C. Because fish remains recovered from Excavation Area B have been omitted from my dissertation, Excavation Area B will not be discussed further here. All subsequent use of the term Upper Midden refers to Excavation Area A, and subsequent use of the term House Feature 5 (HF.5) refers to Excavation Area C.

The Upper Midden (Excavation Area A) deposit is more than 3 m deep and is composed of layers of shells, bone, and fire-cracked rock interspersed with "discrete single or lenticular sand or silt beds" (Mason *et al.,* 2008:25, 36) (Figure 4.6). The Upper Midden was excavated using the stratigraphic method, by digging in "natural layers" according to changes in the "lithologic characteristics of the sediments" (Hilton, 2002: 143). In accordance with the work completed by Hilton (2002: 143), these "natural layers" are described as Lithostratigraphic levels here.

Figure 4.6. Photograph of the Upper Midden profile. Photograph by Jeanne Schaaf, NPS.

The Upper Midden (Excavation Area A) is comprised of seventeen 1x1 m excavation units that form a 3x5 m block with two additional excavation units attached to the southeastern quadrant (Figure 4.5). The excavation block is on top of the midden adjacent to Housepit 1, on the highest point of the bedrock landform. This location was chosen because human skeletal remains and numerous other cultural materials were discovered eroding from the hill/midden (Hilton, 2002). This location was also the target of extensive vandalism efforts that resulted in the loss of a significant amount of data (Hilton, 2002).

In an effort to recover as much data as possible before it was irretrievably lost, NPS personnel focused recovery efforts in Excavation Area A (Figure 4.5) in 1997. During the 1997 field season, all sediments were dry-screened though 0.64 centimeters (cm) [1/4inch (in)] mesh. The use of a large mesh size undoubtedly resulted in the loss of a substantial number of fish bones (Hilton, 2000). Excavation Area A remained the focus of exploration during the 1998 field season. All sediments were dry screened through 0.64 cm (1/4 in) mesh, which was consistent with the previous year. All faunal materials larger than 0.64 (1/4 in) were retained and were submitted for zooarchaeological analysis. In 1999, a small portion of Excavation Area A (Unit

2S2E) was briefly re-opened to excavate a column sample, which measured 20 x 20 x 157 cm (Hilton, 2000). The entire column sample was collected and brought to the lab for systematic analysis (Hilton, 2002). Sediments were passed through 0.32 cm (1/8 in) mesh in the lab so the Upper Midden fish bone assemblage would be comparable to the Lower Midden assemblage.

Excavation Area C (HF.5) was excavated using the stratigraphic method during the 1999 field season. All sediments were dry screened and passed through 0.32 cm (1/8 in) mesh (Hilton, 1998). Six excavation units (Figure 4.5) were exposed; however, because of the excavation strategy employed, only one unit (7S13E) measured a full 1 x 1 m (Hilton, 2002). Three of the six excavation units (5S13E, 6S14E, and 7S15E) were truncated by erosion and vandalism, while the remaining two (6S13E and 7S14E) were not completely excavated to form a balk (to retain stratigraphic details). All of the fish remains analyzed for this dissertation were recovered from excavation unit 7S13E, and therefore, descriptions focus on this unit.

Lower Midden

The Lower Midden deposit is mainly composed of irregular beds of clay, silt, volcanic ash, and ochre dotted with individual cobbles (Hilton, 2002) (Figure 4.7). These Lower Midden deposits are highly compressed and distinct sediment layers are visible (Mason *et al.,* 2008). The Lower Midden sediments differ markedly from the Upper Midden sediments (Figure 4.6), which are comprised of loosely compressed and undifferentiated shell and bone deposits (Jeanne Schaaf, personal communication, 2011).

The Lower Midden is comprised of sixteen northwest to southeast-oriented 1x1 m excavation units that formed a 2x6 m excavation block (Figure 4.5) (Tennessen, 2009). The Lower Midden was excavated following natural layers using the lithostratigraphic method (Jeanne Schaaf, personal communication, 2011). Excavation of the Lower Midden locus began with clearing a ca. 2 meter long profile of the erosional exposure in 1997 (Figure 4.7); excavation continued until 2000.

Figure 4.7. Photograph of the Mink Island Lower Midden Profile. After removal of slumped material and shallow profile cleaning, which followed the contours of the erosional cut. The in situ material under Schaaf was excavated 1999-2000. 1997 NPS photograph by M. Etnier.

During 1997, investigations of the Lower Midden consisted of a controlled surface collection coupled with the preparation of a vertical profile (Figure 4.7). Where the exposed face of the Lower Midden required the removal of more than shallow surface cleaning (2LS1LW, 2LS1LE, and 2LS2LE), the sediments were removed by natural and arbitrary levels and screened through 0.32 cm (1/8 in) mesh. A provisional grid was established that tied the profile work to the permanent datum set in 1996. The profile work was completed by hand trowelling and artifacts were recorded *in situ* (Jeanne Schaaf, personal communication, 2011). During 1998, excavation continued and all sediments were water-screened through 0.32 cm (1/8 in) mesh. One-liter bulk samples were collected for laboratory processing (Jeanne Schaaf, personal communication, 2011). During the 1999 field season, excavations of the Lower Midden focused on the southern row of the block (Tennessen, 2009). All excavated sediments were water-screened through 0.16 cm (1/16 in) mesh and bulk samples were collected from each level and unit for lab processing (Jeanne Schaaf, personal communication, 2011). During the 2000 field

season, all excavated sediments were water-screened through 0.16 cm (1/16 in) mesh and bulk samples were collected from each level and unit for lab processing. Excavations were halted upon reaching sterile sediments (Jeanne Schaaf, personal communication, 2011).

Lithostratigraphic Divisions

Upper Midden (Excavation Area A)

Artifactual evidence suggests that the Upper Midden Excavation Area A represents a multi-use zone where humans were interred, waste (lithic, bone, ivory, wood, pottery, etc.) was discarded, and food was processed (fish, shellfish, mammals, birds, etc.) (Hilton, 2002). A profile of the major lithostratigraphic levels from Excavation Area A are presented in Figure 4.8. All but three litostratigraphic divisions (features 4f, 4g, and 4i) are comprised of discarded lithic, floral, and faunal remains (Hilton, 2002).

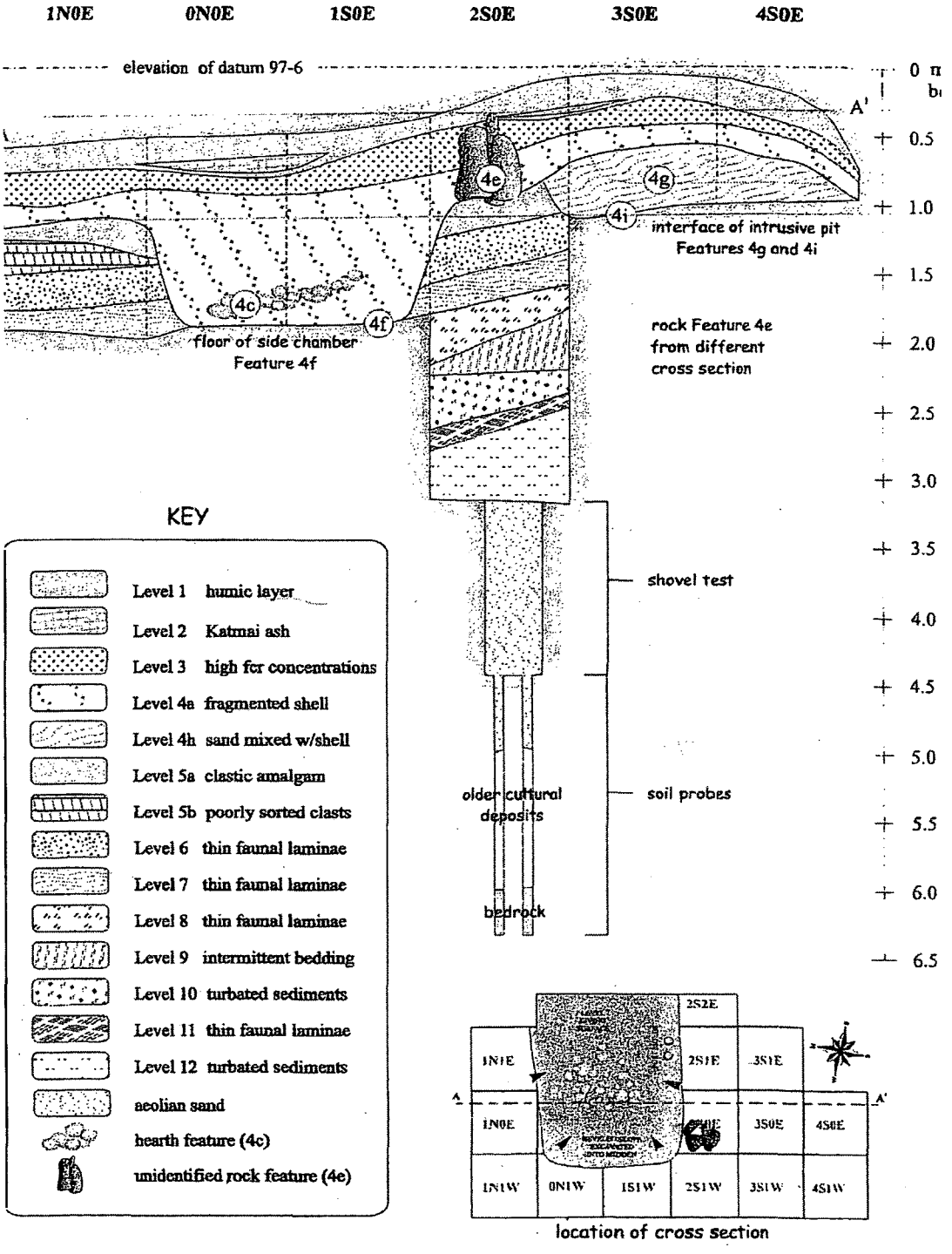


Figure 4.8. Profile of Mink Island Upper Midden Excavation Area A. (Hilton 2000, Figure 6.2).

Level 13 contains deep cultural deposits (contemporaneous with the Ocean Bay I phase) and a layer of sterile sand (Figure 4.8) (Hilton, 2002). In unit 2S0E, Hilton (2002) probed the soil beneath level 13 to a depth of 596 cm below the datum (cm bd). The probing stopped when Hilton (2002) encountered either a bedrock (R) or regolith (C) horizon, which halted progress. The layer of culturally sterile sand ranged from 310 to 490 cm bd. Directly beneath the sterile sand layer was a layer of crushed mussel shells, over a few charcoal flakes and a sea mammal bone. Approximately 5 cm below the sea mammal bone, a layer of ochre was visible. A basalt flake was found between the ochre layer and tephra layer (Hilton, 2002). The cultural sediments found beneath Excavation Area A date to the Ocean Bay I phase (5585 cal. BP; Beta-130087) suggesting connection with the Lower Midden component (Hilton, 2002: 155).

Level 12 is the oldest lithostratigraphic level to contain cultural materials and still be associated with the post-abandonment reoccupation of the site (Takli Cottonwood phase) (Hilton, 2002). Only one unit (2S0E) was excavated to level 12 (Figure 4.8), therefore, all of the artifacts and features were recovered from a 1x1 m area. Within level 12, Hilton (2002) uncovered three small postmolds that extended into the sterile sand layer found in level 13 as well as a layer of mixed secondary deposits. Hilton's (2002) discovery led him to suggest that the first people to reoccupy the site after the abandonment (4100-2000 cal. BP) camped directly on top of the sand dune. Shortly afterwards, the area became a refuse dump, which grew larger in the southern portion of the excavation unit (Hilton, 2002).

Levels 6-11 represent a series of individual dump episodes variously consisting of discarded shells, fish bones, and sea urchins (Figure 4.8) (Hilton, 2002). The individual dump episodes are visible as "thin lamina separated according to taxa" (Hilton, 2002: 157). Because the individual laminae were visible in cross section, the sediments in these levels likely suffered little post-depositional turbational disturbance (Hilton, 2002). Levels 11, 8, and 7 consist of thin layers of faunal materials, indicative of *in situ* food processing. Other than a thin layer (<1 cm) of dark sediment separating levels 8 and 7, soils and mineral sediments were lacking from these levels. Levels 9 and 6 consist of mixed (secondary deposits) sediments infused with thin layers (<1 cm) of shell and bone (Hilton, 2002). On several occasions, *in situ* shellfish and fish processing episodes punctuate the mixed secondary dumping episodes (Hilton, 2002). Level 10 consists of a dark brown/black sandy matrix, which is composed of mixed secondary dump

episodes comprised of potsherds, fire cracked rocks, lithic artifacts, charcoal, sea mammal bones, fish bones, and shellfish remains (Hilton, 2002).

Levels 4 and 5 are composed of a random mixture of shell, bone, and other materials that were difficult to differentiate and document (Figure 4. 8) (Hilton, 2002). Stratigraphic divisions that were noticeable in profile were exceedingly difficult to distinguish while excavating (Hilton, 2002). Because of the mixed nature of the sediments, Hilton (2002) was able to document the major lithostratigraphic distinctions, while the more subtle distinctions were lost.

Level 3 contains massive amounts of fire-cracked rock and charcoal, byproducts of steam baths for fish and shellfish processing (Figure 4.8) (Hilton, 2002). In addition, the dark matrix of level 3 contains numerous bone fragments and shells (Hilton, 2002). The Level 3 deposit represents a discard zone, without any associated features or structures. This level contains the most recent deposit of cultural origin in Excavation Area A (535 cal. BP; Beta-109926) (Hilton, 2002).

Level 2 is non-cultural in origin and consists of a layer of volcanic ash from the 1912 eruption of Mt. Katmai (Figure 4.8) (Hilton, 2002). Concentrations of Katmai ash along the coast of Katmai National Park and Preserve are as much as 50 cm deep. However, in Area A, the tephra was limited to small pockets no more than 20 cm deep (Hilton, 2002).

Level 1 is comprised of culturally sterile sediments and soils that accumulated at the site since the 1912 eruption (Figure 4.8) (Hilton, 2002). Level 1 is found across all of the units in Excavation Area A, and is covered by a matt of cow parsnip (*Heracleum lanatum*) and *Elymus* grass. There is evidence that the taproot of the cow parsnip disturbed the substrate in the upper levels in Excavation Area A (Hilton, 2002).

Upper Midden (Excavation Area C)

Artifactual evidence suggests that the Upper Midden Excavation Area C (House Feature 5) (Figure 4.5) represents two distinct living surfaces that are separated by dump episodes composed of faunal materials (e.g. fish, shellfish, mammals, birds, etc.) and other waste

products (e.g. lithic, bone, ivory, wood, pottery, etc.) (Hilton, 2002). A profile of the major lithostratigraphic levels from Excavation Area C is presented in Figure 4.9.

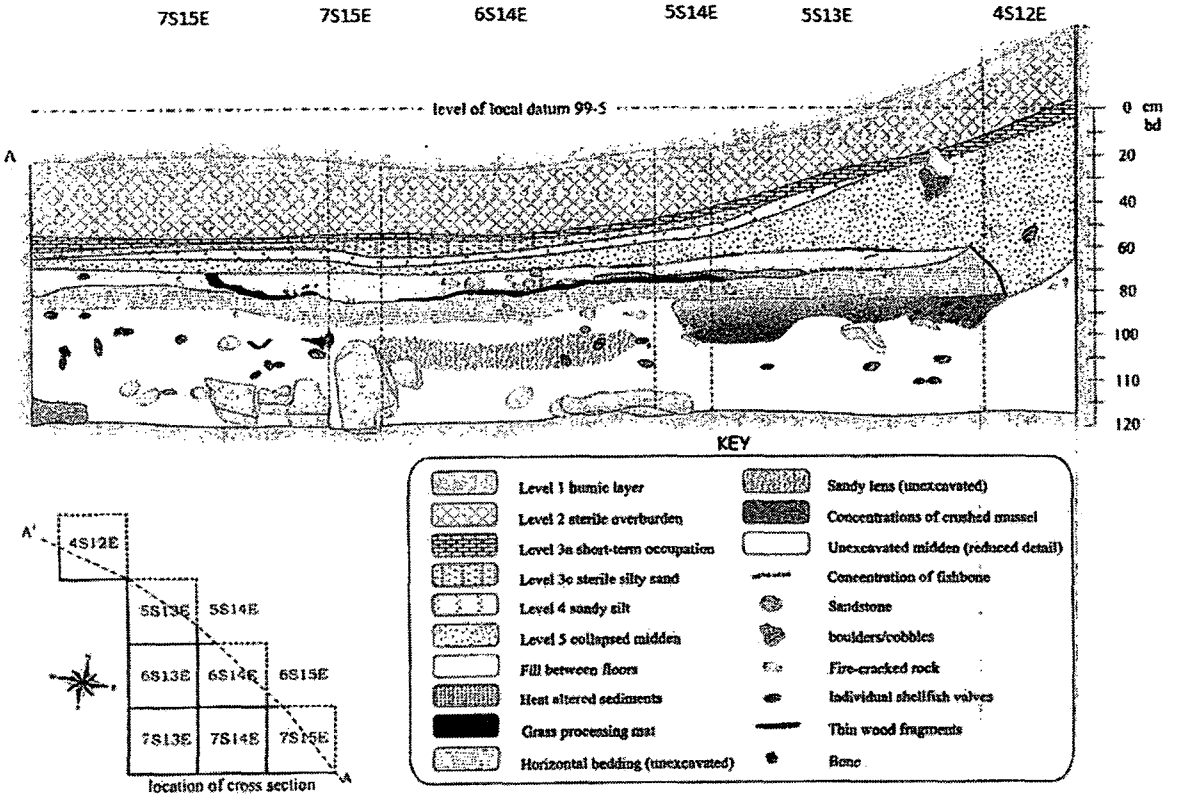


Figure 4.9. Profile and Planview of Excavation Area C (House Feature 5). (Hilton, 2000; Figure 6.4).

Level 6 consists of a living surface associated with House Feature 5 (Figure 4.9). Due to the ending of the field season, excavation stopped at the base of Level 6. However, nearby profiles indicate that multiple living surfaces were present approximately 10 cm below the Level 6 house floor (Hilton, 2002). Numerous fragmented shells, bones, and fire-cracked rocks were recovered from the living surface (Hilton, 2002).

Level 5 is comprised of secondary dump deposits composed of shells, bones, and fire-cracked rocks discarded from the above hillside (Figure 4.9). Midden accumulations on the northwestern quadrants (uphill) are deeper than those on the southeastern quadrants (downhill) (Hilton, 2002).

Level 4 represents a thin deposit (<4 cm) of wind-blown sediments that settled on the lee side of the hillside (Figure 4.9). This deposit is non-cultural in origin (Hilton, 2002).

Level 3 signifies a short-term re-occupation of House Feature 5; deposits are thin (<5 cm) (Figure 4.9). Large fragments of shell, fire-cracked rock, and bones are present. Level 3 likely represents the last residential activity at the Mink Island site (Hilton, 2002).

Level 2 consists of a mixed ash (Katmai ash) and aeolian sand deposit that is devoid of cultural materials and L*evel 1* is limited to the sod layer (e.g. cow parsnip and Elymus Grass) and cultural materials are absent (Figure 4.9) (Hilton, 2002).

Lower Midden

A detailed Lower Midden profile and associated level descriptions are not included in this discussion because geoarchaeological analysis (pH, grain size, etc.) is ongoing and level descriptions are not presently available (Jeanne Schaaf, personal communication, 2011). A generalized profile and a description of the major stratigraphic divisions (Zones I, II, III) are, however, available for three excavation units (1LS2LW, 1LS0LE, 1LS2LE), which are centrally located within the Lower Midden excavation block (Figure 4.10). The available zone descriptions from the three excavation units will be used here as a proxy for the remaining Lower Midden excavation units. The temporal zonation approach used here is similar to that used by Fitzhugh (2004:26-28) at the Tanginak Spring site on Sitkalidak Island (Kodiak Archipelago), and provides a means to link cultural expression with major stratigraphic divisions. Descriptions of the major stratigraphic divisions are covered later in the Mink Island Temporal/Cultural Zonation section of this chapter.

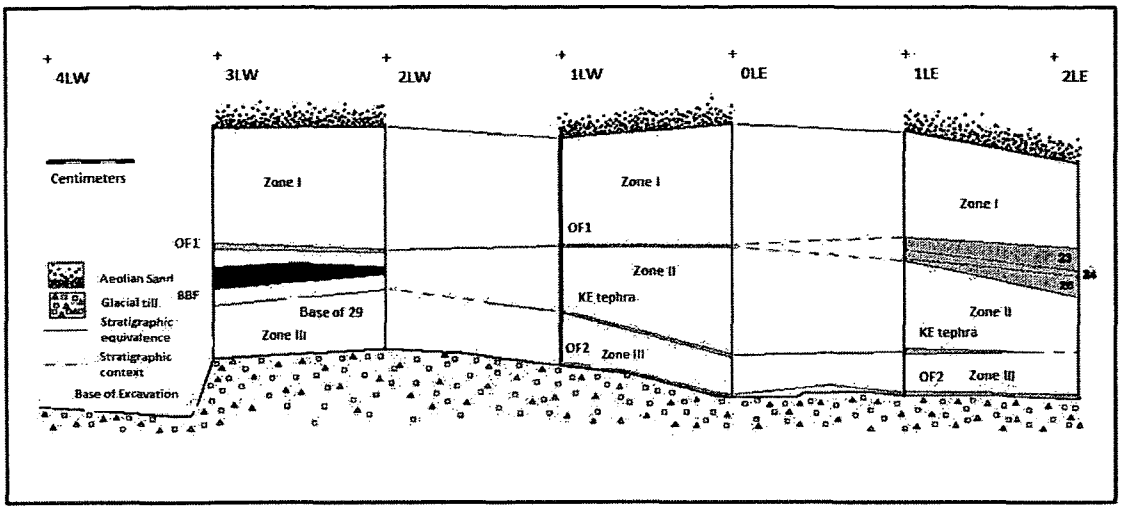


Figure 4.10. Profile of the Mink Island Lower Midden Excavation Units. From Tennessen (2009).

Radiocarbon Dates

Upper Midden (Excavation Areas A and C)

Nineteen radiocarbon dates were obtained from the Upper Midden locus by Hilton (2002: Table 5.2), and are presented in Table 4.1. The Upper Midden radiocarbon dates range between 455 and 1955 median cal. BP (Hilton, 2002: Table 5.2). Fifteen of the nineteen dates collected by Hilton (2002: Table 5.2) were obtained from Excavation Area A of the Upper Midden. Three dates were collected from Excavation Area C and one date was collected from Excavation Area B (Hilton, 2002). With the exception of one incongruous date obtained from level 7 in Excavation Area A, the radiocarbon sequence reflects stratigraphic superposition (Hilton, 2002). The older of two dates from level 7 (Beta-114543) is about 350 years older than the surrounding strata, even though the sediments from which the sample was collected was "clearly undisturbed" (Hilton, 2002: 134). Hilton (2002: 134-136) proposed two possible reasons for this discrepancy: 1) The charcoal sample was collected from the heart of an old drift log, or 2) The sample was collected from a section of wood that remained in "systemic context" for several generations. Eighteen of the nineteen-radiocarbon dates collected from the Upper

Midden were derived from charcoal samples. A single radiocarbon date (Beta-149293) was collected from grass blades associated with a feature within Excavation Area C (Hilton, 2002).

Table 4.1. Upper Midden radiocarbon date calibrations ordered by excavation area and then by stratigraphic level. After Hilton (2002: pg. 135, Table 5.2). [1] Calibrated age ranges report a 2-sigma standard deviation. Radiocarbon ages were not provided.

Laboratory Designation	Excavation Area	Excavation Unit	Stratigraphic level	Material Type	Technique	Calibrated Age Range[1] (Years BP)	Calibrated Intercept (Years BP)
Beta-109926	A	1N1W	3	Charcoal	ext. count	650-495	535
Beta-109927	A	1S1W	4a	Charcoal	standard	915-675	745
Beta-109928	A	1S0E	4f	Charcoal	ext. count	1055-550	745
Beta-109929	A	0N1E	4d	Charcoal	ext. count	915-665	735
Beta-114541	A	1S1W	5a	Charcoal	standard	960-725	910
Beta-109930	A	2S0E	6	Charcoal	standard	970-735	915
Beta-114542	A	1N1W	6	Charcoal	AMS	960-755	915
Beta-147721	A	1S1W	7	Charcoal	AMS	1550-1390	1510
Beta-114544	A	2S1E	8	Charcoal	ext. count	1560-1270	1375
Beta-109931	A	2S1E	9	Charcoal	standard	1620-1360	1520
Beta-130085	A	2S0E	10	Charcoal	standard	1710-1390	1540
WSU-5044	A	2S0E	11	Charcoal	standard	1990-1725	1875
Beta-130086	A	2S0E	12	Charcoal	ext. count	2120-1835	1955
Beta-130090	C	5S13E	>6	Charcoal	ext. count	530-305	490
Beta-149293	C	6S14E	6d	Grass	standard	660-450	530
Beta-130091	C	5S13E	>6	Charcoal	standard	740-555	665

Lower Midden

Twenty-seven radiocarbon dates were obtained from the Lower Midden locus and are presented in Table 4.2. The Lower Midden radiocarbon dates range between 4045 and 6590 median cal. BP (Jeanne Schaaf, personal communication, 2011). Several of the radiocarbon dates are out of sequence, suggesting a lack of stratigraphic superposition (Schaaf, 2009: 37). While the lack of stratigraphic superposition complicates site interpretation, it is not surprising considering a combination of natural and cultural processes played a large role in the

accumulation of sediments of the Lower Midden locus. To overcome some of the radiocarbon date reversals, several litostratigraphic levels have been combined to form averaged calibrated median intercept radiocarbon dates (Table 4.3).

Table 4.2. Lower Midden radiocarbon dates after Tennessen (2009: 352, Appendix B), sorted by conventional age. [1]Dates reported are based on the Libby ^{14}C half-life of 5568 years. Conventional ages (1-sig. S.D.) have been normalized to the modern pee-dee-belemnite-1 international standard based on measured $\delta^{13}C$ values ranging between -21.5‰ and -29.0‰ (Stuvier and Polach, 1977). [2]Calibrated age ranges report a 2-sig. S.D.

Laboratory Designation	Excavation Unit	Strat. Level	Material Type	Dating method	Conventional Age[1] (14C Yrs BP)	Calibrated Age Range[2] (Years BP)	Calibrated Intercept (Years BP)
Beta-130102	1LS2LW	4	Charcoal	Ext. count	3690±130	4415-3686	4045
Beta-130095	1LS3LW	n/a	Charcoal	AMS	4180±40	4840-4570	4745
Beta-130099	0LN1LE	2	Charcoal	AMS	4420±30	5225-5190	4980
Beta-130098	0LN2LE	2	Charcoal	AMS	4440±30	5275-4885	5040
Beta-130107	0LN0LE	8	Charcoal	AMS	4440±40	5285-5155	5040
Beta-130100	1LS2LW	3	Charcoal	AMS	4450±30	5280-4960	5045
Beta-130104	0LN1LE	6	Charcoal	AMS	4450±40	5290-4880	5045
Beta-130103	0LN1LW	5	Charcoal	AMS	4480±40	5295-4885	5050
Beta-130101	1LS2LE	4	Charcoal	AMS	4510±40	5310-4990	5130
Beta-130096	0LN2LE	1	Charcoal	AMS	4520±20	5310-5340	5155
Beta-130111	1LS0LE	5	Charcoal	AMS	4520±30	5305-5050	5155
Beta-130110	0LN0LE	10	Charcoal	AMS	4530±40	5315-5045	5290
Beta-130109	0LN3LW	9	Charcoal	AMS	4560±40	5305-4980	5175
Beta-130097	0LN1LE	1	Charcoal	AMS	4620±40	5465-5300	5425
Beta-130106	0LN1LW	7	Charcoal	AMS	4670±30	5465-5310	5415
Beta-130094	1LS2LW	n/a	Charcoal	AMS	4680±40	5575-5310	5385
Beta-130105	0LN1LW	7	Charcoal	Ext. count	4780±80	5650-5315	5515
Beta-130108	0LN1LW	8	Charcoal	AMS	4780±40	5600-5340	4780
Beta-130093	2LS1LE	17	Charcoal	AMS	5580±40	6265-5995	6175
Beta-110269	2LS1LW	23	Charcoal	AMS	5929±50	6870-6655	6750
Beta-110267	2LS1LW	23	Charcoal	AMS	6180±50	7195-6905	7025
Beta-110268	2LS0LE	23	Charcoal	AMS	6300±50	7265-7045	7205

Mink Island Temporal/Cultural Zonation

Upper Midden

For the purpose of this analysis, the Upper Midden (Excavation Areas A and C) is divided into four temporally distinct zones (UM I, UM II, UM III, and UM IV) (Table 4.3). These zones are arranged from youngest to oldest. Boundaries between the zones follow intact natural or cultural strata that have been tracked across multiple excavation units within Upper Midden Excavation Areas A and C.

Table 4.3. Upper and Lower Midden radiocarbon dates, zones, and cultural affiliations. [1]From Dumond, 2005, [2]From Clark (1992b).

Locus	Levels	Age (cal. BP)	Temporal/ Cultural Zone	Cultural Phase	Cultural Tradition
Upper Midden	3, 4a, 4f, 4d	750-455	UM I	Kukak Mound	Thule[1]/Koniag[2]
	HF.5	640-510	UM I	Kukak Mound	Thule[1]/Koniag[2]
	5a, 6	1000-750	UM II	Kukak Mound/ Kukak Beach	Mixed Thule[1]/Koniag[2] and Norton[1]/Kachemak[2]
	7-10	1600-1000	UM III	Kukak Beach	Norton[1]/Kachemak[2]
	11-12	2000-1600	UM IV	Takli Cottonwood	Norton[1]/Kachemak[2]
Lower Midden	1-13, PBF, SB1	5400-4100	LM I	Ocean Bay II	Ocean Bay
	14-39, OF1	6700-5400	LM II	Ocean Bay I	Ocean Bay
	40, 46-49, KE Tephra	7500-6700	LM III	Unnamed	Paleoarctic

UM I dates between 750 and 455 cal. BP and roughly corresponds with the Kukak Mound phase of the Thule tradition (Table 4.3) (Koniag on Kodiak Archipelago) (Clark, 1992b; Dumond, 1987a; Hilton, 2002; Jeanne Schaaf, personal communication, 2011). UM I encompasses the culturally sterile soils covering the Upper Midden locus through litostratigraphic level 4. Associated archaeological deposits variously consisted of culturally sterile soils (Level 1), tephra deposits (Level 2), steam bath-related artifacts (Level 3), and mixed secondary dump deposits consisting mainly of shell and bone fragments (Levels 3 and 4) (Hilton, 2002). Associated median intercept calibrated radiocarbon dates (2 sigma) for UM I include 535

BP (level 3) and 742 BP (levels 4a, 4d, 4f) (Hilton, 2002; Jeanne Schaaf, personal communication, 2011) (see Table 3). UM I is associated with the Little Ice Age (LIA), which lasted from ca.550 to 50 cal. B.P (Solomon *et al.*, 2007). During the Little Ice Age, climatic conditions were markedly cooler in the northern hemisphere (Calkin *et al.*, 2001). Distinct glacial advances were observed in the region around 750, 500, 350, and 150 cal. BP (Calkin *et al.*, 2001).

UM II dates between 1000 and 750 cal. BP and represents a transitional phase where Kukak Mound phase of the Thule tradition (Koniag on Kodiak Archipelago) and Kukak Beach phase (Norton/Kachemak traditions) peoples intermingled and influenced each-other at the Mink Island site (Clark, 1992b; Dumond, 1987a; Hilton, 2002). UM II encompasses lithostratigraphic levels 5 and 6, which consisted mainly of mixed secondary dump deposits (bone and shell fragments) (Hilton, 2002). Lithostratigraphic levels 5 and 6 have been combined here and have a median intercept calibrated radiocarbon date (2 sigma) of 913 BP (Hilton, 2002; Jeanne Schaaf, personal communication, 2011) (Table 4.3). UM II climatic conditions fall within the Medieval Warm Period (MWP), when mean annual July temps reached as high as 14 degrees C on the North Pacific coast (Heusser *et al* 1985; Mann *et al.*, 1998; Mann, 2003).

UM III dates between 1600 and 1000 cal. BP and roughly corresponds with the Kukak Beach phase of the Norton/Kachemak traditions (Clark, 1992b; Dumond, 1987a; Hilton, 2002; Jeanne Schaaf, personal communication, 2011). UM III encompasses lithostratigraphic levels 7 through 10, which is comprised of a series of individual dump episodes consisting of fish, sea urchins, and other shells (Hilton, 2002). Lithostratigraphic levels 7 through 10 have a median intercept calibrated radiocarbon date (2 sigma) of 1486 BP (Hilton, 2002; Jeanne Schaaf, personal communication, 2011) (Table 4.3). UM III climatic conditions are associated with the transition between the Medieval Warm Period and the Neoglacial period. Climatic conditions are cooler and wetter than the preceding MWP but warmer and drier than the Neoglacial period.

UM IV dates between 2000 and 1600 cal. BP and roughly corresponds with the Takli Cottonwood phase of the Norton/Kachemak traditions (Clark, 1992b; Dumond, 1987a; Hilton, 2002; Jeanne Schaaf, personal communication, 2011). UM IV encompasses litostratigraphic levels 11 and 12, which is comprised of mixed secondary bone deposits. Lithostratigraphic Levels 11 and 12 have a median intercept calibrated radiocarbon date (2 sigma) of 1915 BP

(Hilton, 2002; Jeanne Schaaf, personal communication, 2011) (Table 4.3). UM IV climatic conditions are associated with a relatively abrupt shift from cooler temperatures and stormy conditions, to warmer temperatures and less stormy conditions (Heusser *et al.*, 1985).

Period of Site Abandonment (Occupational Hiatus)

The Upper and Lower Midden loci are separated by a 1.5 meter-thick culturally sterile sand deposit that corresponds with a period of site abandonment (occupational hiatus) between 2000 and 4100 cal. BP (Hilton, 2002; Mason *et al.*, 2008). The period of abandonment roughly corresponds with a period of increased volcanic activity (Riehle *et al.*, 2000; VanderHoek, 2009) and increased storminess associated with Neoglaciation (Heusser *et al.*, 1985; Mason and Jordan, 1993).

From 4000 until 3400 cal. BP, four major volcanic eruptions spread ash around the region (Riehle *et al.*, 2000; VanderHoek, 2009). These eruptions also caused significant tectonic movements (Riehle *et al.*, 1998), which may have altered the shoreline configuration and changed the sediment budgets in the region (Hilton, 2002; Jordan and Maschner, 2000). Evidence of these phenomena is visible on Little Takli Island, which was impacted by the Mt. Katmai (Novarupta) eruption in 1912 (Hilton, 2002). Over the 90-years following the Mt. Katmai eruption, 12 meter-deep sand dunes formed on Little Takli Island (Hilton, 2002).

The occupational hiatus at the Mink Island site also roughly corresponds to the period of increased storminess associated with Neoglaciation (Heusser *et al.*, 1985; Mason and Jordan, 1993). The climate in the region became cooler and wetter during this period, which caused several glaciers along the central Alaska coast to advance. Glacial advancement caused the sediment load of the Gulf of Alaska to increase, depositing large amounts of sand on the continental shelf south of Kodiak Island. Westerly winds eventually moved these sediment deposits from the continental shelf to the beaches on Mink Island and the surrounding coastal area. Sand dunes formed in areas surrounding beach grasses (*Elymus* spp.), which recently spread into the region at that time (Mason *et al.*, 2008).

Lower Midden

Following the work of Tennessen (2009), the Lower Midden locus is divided here into three vertically sequential and temporally distinct zones (LM I, LM II, and LM III) (Table 4.3). These zones are arranged from youngest to oldest. Boundaries between the zones follow intact natural or cultural strata that have been tracked across multiple excavation units within the Lower Midden excavation area (Figure 4.10) (Tennessen, 2009). Zone descriptions are based on three excavation units (1LS2LW, 1LS0LE, 1LS2LE), which serve as a proxy for the remaining excavation units (0LN3LW, 0LN2LW, 0LN1LW, 0LN0LE, 0LN1LE, 0LN2LE, 1LS3LW, 1LS1LW, 1LS1LE, 2LS1LW, 2LS0LE, 2LS1LE, and 2LS2LE).

LM I dates between 5400 and 4100 cal. BP and roughly corresponds with the Ocean Bay II phase of the Ocean Bay tradition (Dumond, 1987a; Jeanne Schaaf, personal communication, 2011; Tennessen, 2009) (Table 4.3). LM I encompasses the sterile sand covering the Lower Midden locus to the top of Ochre Floor 1 (OF1), a thin (< 1 cm thick) ochre-stained living surface that is most likely associated with a small, shallow, oval-shaped temporary structure (Mason *et al.*, 2008; Jeanne Schaaf, personal communication, 2011; Tennessen, 2009) (Table 4.3). OF1 is present in 1LS0LE and 1LS2LW, but absent from 1LS2LE (Jeanne Schaaf, personal communication, 2011). Although OF1 is absent from 1LS2LE, stratigraphic data suggests that OF1 is contemporaneous with arbitrary levels 23, 24, and 25 (Jeanne Schaaf, personal communication, 2011) (Table 4.3). Associated median intercept calibrated radiocarbon dates (2 sigma) for LM I include 5047 BP (levels 1-6) and 5340 BP (levels 7-12, features PBF and SB1). Level 13 is also included in LM I, however radiocarbon dates are lacking for this litostratigraphic level (Jeanne Schaaf, personal communication, 2011) (Table 4.3). Climatic conditions linked with LM I are associated with dramatic cooling at the onset of the Neoglacial (Heusser *et al.*, 1985).

LM II dates between 6700 and 5400 cal. BP and roughly corresponds with the Ocean Bay I phase of the Ocean Bay tradition (Dumond, 1987a; Jeanne Schaaf, personal communication, 2011; Tennessen, 2009) (Table 4.3). LM II extends from the bottom of Ochre Floor 1 (OF1) to the top of the KE Tephra layer, or level 29 depending on excavation unit. The KE Tephra layer represents a discrete ash fall event that was remobilized for a short period after initial deposition (Mason *et al.*, 2008). The KE Tephra layer is not present in unit 1LS2LW; it was

apparently truncated by a later occupation. The bottom of level 29 is considered stratigraphically equivalent with the KE Tephra layer (Table 4.3) (Mason *et al.,* 2008). Associated median intercept calibrated radiocarbon dates (2 sigma) for LM II include 5385 BP (level 14 and OF1) and 6530 BP (levels 33-39). Levels 15-32 are also included in LM II, however radiocarbon dates are lacking for these litostratigraphic levels (Jeanne Schaaf, personal communication, 2011) (Table 4.3). Lower Midden Zone II climatic conditions are associated with a transitional period between the end of the Hypsithermal and the beginning of the Neoglacial when the climate began to cool (Heusser *et al.,* 1985).

LM III dates between 7500 and 6700 cal. BP and roughly corresponds with the Paleoarctic tradition (Dumond, 1987a; Jeanne Schaaf, personal communication, 2011; Tennessen, 2009). LM III extends from the KE Tephra layer, or level 29 depending on excavation unit, to the sterile glacial till layer below the Lower Midden locus (Table 4.3) (Tennessen, 2009). The associated median intercept calibrated radiocarbon date (2 sigma) for LM III is 6590 BP for level 40 and the KE Tephra level. Levels 45-51 are also included in LM III, however radiocarbon dates are lacking for these litostratigraphic levels (Jeanne Schaaf, personal communication, 2011) (Table 4.3). LM III climatic conditions are associated with the transitional period at the end of the Hypsithermal, a warm and dry period when mean average July temperatures in the region reached more than 15 degree C (Heusser *et al.,* 1985).

Features

Five surface depressions (housepits) are visible on the bedrock landform where the Mink Island site is situated (Hilton, 2002) (Figure 4.4). Four of the five housepits (1-4) are easily identifiable; however, housepit 5 is more difficult to recognize because it has been damaged by erosion and vandalism (Hilton, 2002). Housepit 1 (HP1) is near the top of the bedrock landform (Figure 4.4) adjacent to a ca.2.2 m-deep midden, which is within Excavation Area A. Descriptions of HP1 are included here because the occupants of HP1 were likely responsible for the midden accumulation. Excavation Area B is associated with Housepit 3, and Excavation Area C is associated with Housepit 5 (HF.5). Because Excavation Area B is not included in my dissertation, it is not discussed further here. Surface and subsurface features from the Upper

Midden (Excavation Areas A and C) and the Lower Midden loci are presented in the following paragraphs. In addition to the housepit surface features, the Mink Island site also contains several house floors, hearths, storage pits, and postmolds (Hilton, 2002).

Upper Midden (Excavation Area A)

Housepit 1 has well-defined southern and western margins and less well defined northern and eastern margins (Hilton, 2002). The diameter of the housepit is difficult to assess because of the lack of definition in the northern and eastern margins; however, Hilton (2002) estimates it to be ca. 8 m. On the surface, HP1 appears to be round in plan; however, the presence of a 1.8 x 3 m subsurface chamber indicates a side room (Hilton, 2002). The chamber floor (feature 4f) is approximately 1.2 m below the surface (Hilton, 2002). HP1 and the adjacent side room cover a surface area of roughly 56 m^2 (Hilton, 2002). Charcoal from feature 4f generated a radiocarbon date of 700 cal. BP (Beta-109928) (Hilton, 2002). Two additional radiocarbon dates collected from charcoal from fill directly above the Feature 4f fill yielded two dates of 700 cal. BP (Beta- 109927) and 735 cal. BP (Beta-100929).

Features 4g and 4i are comprised of two distinct burial pits containing human remains (Figure 4.8). The burial pits were excavated into the midden deposit adjacent to HP1 near the southern boundary of the site (Hilton, 2002). Details regarding the contents and removal of the human remains are covered in a separate National Park Service document and not discussed further (Hilton, 2002).

Feature 4f represents a satellite room that was excavated into the midden deposits on top of the hill adjacent to HP1 750 years ago (Figure 4.8) (Hilton, 2002). Feature 4f is 2.3 m wide at the top margin and 1.8 m wide at the bottom margin. Because of its size, orientation, and close proximity to HP1, Feature 4f is likely associated with HP1 (Hilton, 2002). No subsurface testing was completed in HP1; therefore, Hilton's (2002) interpretation is unconfirmed. Feature 4f is considered a living surface despite the fact that evidence of a constructed floor (clay, wood, grasses, etc.) is lacking (Hilton, 2002). Features 4f was identified as a living surface because sediments above the floor were randomly oriented and were lightly compacted and sediments beneath at the floor margin were horizontally orientated and highly compacted (Hilton, 2002).

Presence of two postmolds, spaced 24 cm apart, near the southern margin of Feature 4f also supports the interpretation that the feature is a living surface (Hilton, 2002). Because of time constraints, the Feature 4f floor was not excavated, however bifurcated bone socket piece (part of a composite spear), a large flat cobble, a basalt adze bit, two articulating sections of a single leister barb, and the distal tip of a finely crafted unilaterally barbed dart point were found 1-2 cm above the floor surface (Hilton, 2002).

Feature 4e is comprised of a group of four boulders, each of which has been positioned on edge with a vertically oriented long axis (Figure 4.8) (Hilton, 2002). The four stones were found on the surface of Level 5a; however, they were thought to be associated with the Feature 4f living surface (Hilton, 2002). The boulders were arranged so that there was a hollow space in the center. The boulders may have served as a burial marker for the humans interred (Features 4g and 4i) 50 cm to the south (Hilton, 2002).

Feature 4c consists of a hearth that contains fire-cracked rocks and black, greasy, charcoal-laden sediments (Figure 4.8) (Hilton, 2002). Feature 4c is located within the center of the Feature 4f (adjacent to HP1), approximately 10 cm above the Feature 4f floor surface. Hilton (2002) suggests that Feature 4c was used during a short-term reoccupation of the Feature 4f floor.

Upper Midden (Excavation Area C)

Housepit 5 is at the northern extent of the tombolo that connects the Mink Island site with Mink Island (Figure 4.5). The original size and shape of the house are no longer visible because of the combined impacts of erosion and vandalism. Hilton (2002: 181) estimates the house possessed a floor surface area of at least 38 m^2.

Subsurface features associated with Excavation Area C have been omitted because they are not relevant to this discussion. Although a sample of fish remains that were recovered from Excavation Area C were analyzed for this dissertation, they were not associated with living surfaces. The fish remains were obtained from secondary deposits (midden), which were above the House Feature 5 living surface (level 6).

Lower Midden

Feature OF2 is composed of an ochre-stained living surface, which is at the base of the Lower Midden deposit on well-sorted coarse- to medium-grained sand (a figure of the Lower Midden features is not currently available). OF2 represents the first known occupation of the Mink Island site (Schaaf, 2009; Tennessen, 2009). The OF2 floor is basin-shaped and is covered by cultural materials that are approximately 1 cm-deep (Schaaf, 2009). The exact dimensions of the house are unknown because the house was partially eroded and only partially excavated (Schaaf, 2009). Other architectural details associated with OF2 are two perpendicular berms along the living surface and an ochre-stained storage pit below the floor (Schaaf, 2009). Within the storage pit, a finely made boat-shape lamp was discovered on top of a mussel shell and two large basalt blades (Schaaf, 2009). The oldest radiocarbon date for the Mink Island site was obtained from charcoal found below the basalt lamp, which predated dates the house floor by more than 200 years. The older date associated with the storage pit may indicate an older occupation of the site. Alternatively, the older date may indicate that the Mink Island occupants burned driftwood that had been "banked" on Mink Island long before human settlement (Schaaf, 2009).

Feature KE Tephra is composed of a large (10 cm-deep), white ash deposit that blanketed Mink Island ca. 6590 cal. BP (Schaaf, 2009; Jeanne Schaaf, personal communication, 2001). Mink Island was abandoned after the ash fall; however, the site was reoccupied shortly thereafter (Schaaf, 2009). The same white ash deposit was found at the Tanginak Spring site in the Kodiak Archipelago, indicating the ash fall was a widespread phenomenon (Schaaf, 2009).

Feature OF1 is composed of a thin (<1 cm), ochre-stained silt/clay living surface that has a date of 5385 cal. BP (2 sigma) (Tennessen, 2009; Jeanne Schaaf, personal communication, 2011). The OF1 floor is small, shallow, and oval-shaped; it may have been associated with a small, hide-covered, temporary shelter (Schaaf, 2009). The floor surface, covered by a layer of crusty, well-consolidated tephra, was remarkably well preserved (Hilton, 2002; Schaaf, 2009). Separate activity areas for bone needle production, chipped-stone manufacture, and ochre grinding and stockpiling were identified on the OF1 surface (Schaaf, 2009). The excellent preservation of the floor and the thin ash deposit sealing the floor may indicate reasons for site

abandonment. The close association between the OF1 floor and the tephra layer led Schaaf (personal communication, 2011) to hypothesize that an impeding volcanic eruption caused the occupants to make a hurried departure of the site.

Fishing-Related Artifacts

A brief description of fishing-related artifacts (composite fishhooks, leisters, fish scalers, notched stones, grooved stones, net floats) recovered from the Upper Midden locus (Excavation Areas A and C) is presented in this section. Fishing-related artifacts recovered from the Lower Midden locus are not included in this discussion because their analysis is ongoing and not presently available. Through careful examination of how fishing-related technology changes over time, it is possible to reconstruct fishing strategies at a site. Changes in fishing strategies may then be used to make inferences about changing human lifeways. For instance, if prehistoric occupants shifted their focus from fishing in nearshore marine habitats towards riverine habitats, the types of fishing-related artifacts that were used should also shift. Fishing-related artifacts associated with near-shore marine habitats should contain higher frequencies of component fishhooks, and grooved stones. Fishing-related artifacts associated with riverine environments should contain higher frequencies of notched stones and net floats (Kopperl, 2003). If fishing-related artifacts recovered from the Lower Midden locus were available for analysis, it would be possible to reconstruct fishing strategies at Mink Island by measuring temporal changes in fishing-related artifact frequencies, but it is not presently possible to employ this strategy at Mink Island.

Bone and Ivory

Fishhooks- Composite fishhooks are typically used as deep-water fishing implements and are commonly recovered from coastal sites in Southwestern Alaska (de Laguna, 1934). Composite fishhooks are typically composed of a curved shank and a barbed hook (Figure 4.11) (Heizer, 1956). The shank end generally has a small groove or tang on the proximal end to accommodate line attachment, and a small groove or flattened area on the distal end to accommodate the attachment of the barbed hook section (Heizer, 1956). Shanks are often made of a mammal rib, which are naturally curved. Shanks may also be made of more transient materials such as wood, as seen at the Karluk One wet site (Knecht, 1995). Barbed hooks are often constructed of more dense materials, as compared to shanks, that are resistant to breakage such as mammal bones or ivory (Heizer, 1956). The barbed hook portion of the composite varied greatly in size and shape depending on the fish species being targeted (Knecht, 1995). Most hook components were curved and contained a single barb, however twin barbs have been observed in the region (Heizer, 1956).

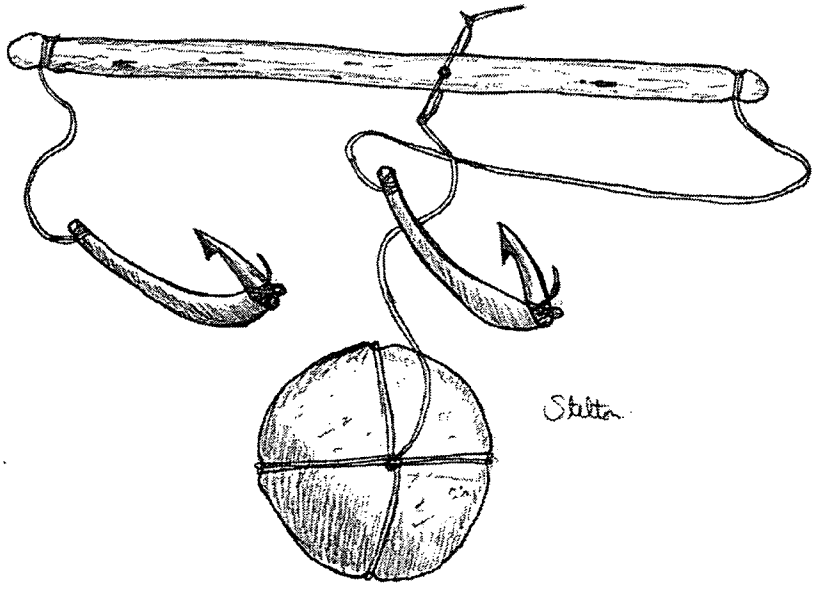


Figure 4.11. Composite fishhooks, spreader bar, and grooved stone for capturing marine fishes. Drawing by Al Stelton.

Fourteen compound fishhook components (1 shank, 13 barbs) were recovered from the Upper Midden locus at the Mink Island site (Hilton, 2000). Ten of the fourteen composite fishhook components are presented in Figure 4.12. Three of the thirteen barbed hooks recovered from Mink Island were constructed out of ivory (Figure 4.12; E and J, one ivory specimen is not shown), the remaining ten were made out of bone (Hilton, 2000). All of the barbed components contained a single barb and evidence of lashing on the proximal end (Hilton, 2000). Two specimens (Figure 4.12; barb E, one not shown) had a single groove incised around the proximal end, and one specimen (Figure 4.12; barb B) had a double groove in the same location to aid in lashing the barbed component to the shank component (Hilton, 2000). A single barbed hook was decorated with a shallow groove carved into the spine (not shown) (Hilton, 2000). Four of the thirteen barbed hook specimens are different from the remaining specimens recovered from Mink Island (Hilton, 2000). These four anomalous barbed hook specimens (Figure 4.12; barbs D, G, and I, one not shown) are straight, less robust, and lack any indication that they were hafted (Hilton, 2000).

Fishhook components were recovered in Excavation Areas A, B, and C (Hilton, 2000). Most of the fishhook components (n=12) were recovered from levels dating to the last 1000 years; and are associated with the Kukak Mound phase of the Thule/Koniag tradition. Two fishhook components were recovered from older contexts. One fishhook component was recovered from Level 7, and dates to 1486 cal. BP and is associated with the Kukak Beach phase of the Kachemak tradition/Norton sub-tradition (Figure 4.12; barb F) (Hilton, 2000, 2002). The final, and oldest, fishhook component was recovered from Level 12, and dates to 1955 cal. BP and is associated with the Takli Cottonwood phase of the Kachemak tradition/Norton sub-tradition (Figure 4.12; barb D) (Hilton, 2000, 2002).

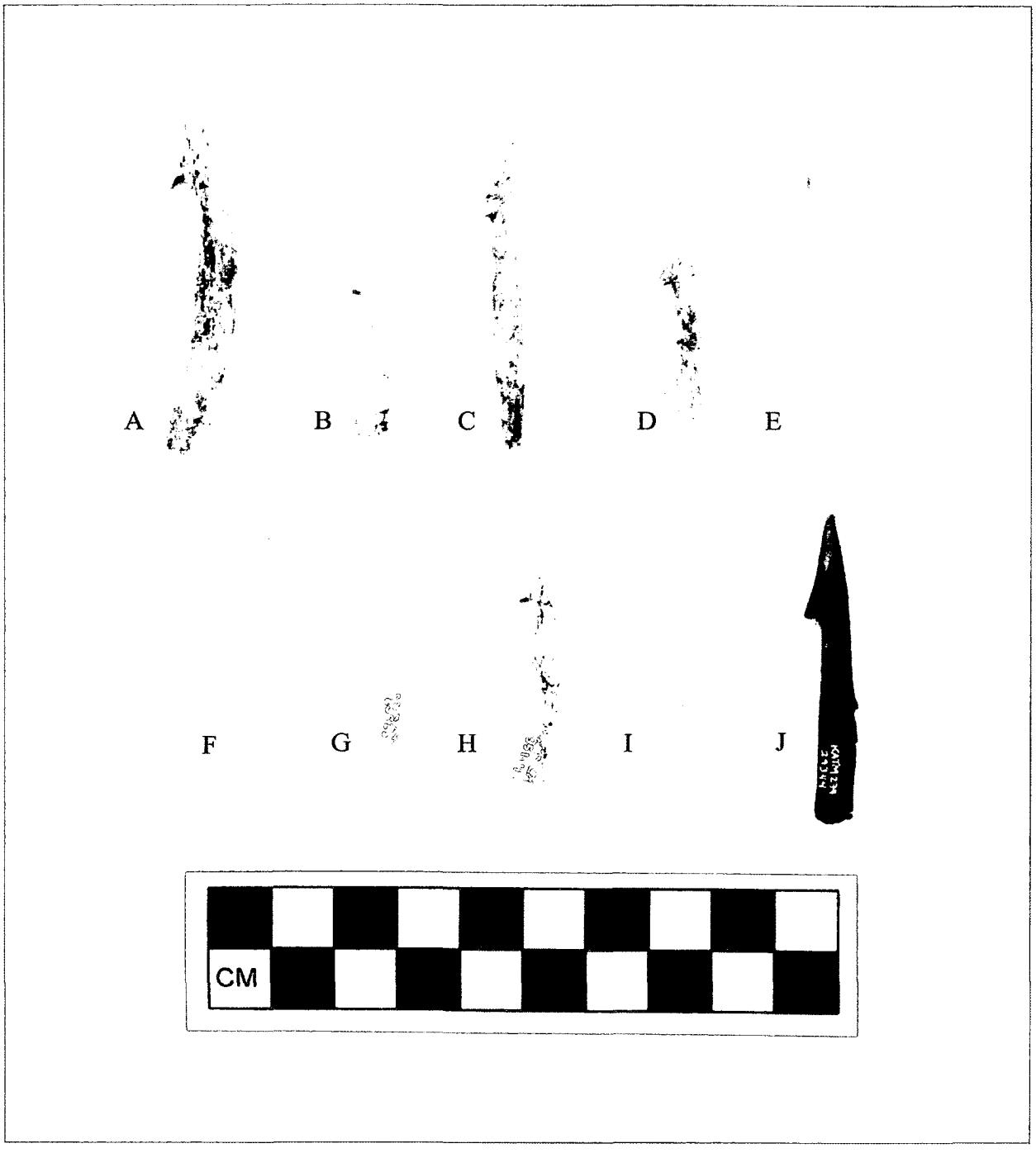


Figure 4.12. Fishhook Components from Mink Island Upper Midden Locus. A=bone barb, Excavation Area C, surface; B=bone barb, Excavation Area C surface; C=bone barb, Excavation Area A, level 6; D=bone barb, Excavation Area A, level 12; E=ivory barb, Excavation Area A, level 4d; F=bone barb, Excavation Area A, level 7; G=bone barb, Excavation Area A, level 5; H=bone barb Excavation Area C, Level 3; I= bone barb, Excavation Area A, level 6; J=ivory barb, Excavation Area B, level 4b (burned).

Leisters- Seven leister components (part of a three-pronged fishing spear) have been identified from Levels 4, 5, and 6 of the Upper Midden locus at Mink Island, which date between 950 and 750 cal. BP (Hilton, 2002). Six of the seven-leister components exhibit a similar morphology; however, the seventh component is significantly different (Hilton, 2002). The six morphologically similar leister components have been identified as the lower barbs of a leister side prong (Hilton, 2002). The seventh leister component may also be a lower barb of a leister side prong; however, the shape of the base and tip make it difficult to interpret. The base of the anomalous leister component is complicated, requiring the base of the articulating side prong to be equally complicated for it to articulate properly. Additionally, the blunt shape of the distal tip would have made it difficult to pierce through the skin and flesh of the prey (Hilton, 2002). Because alternative functional interpretations are lacking, this anomalous bone artifact is classified here as a leister component. The six morphologically similar leister components are also distinct from regional specimens. The Mink Island specimens are more robust and have more barbs than their regional counterparts (Murdoch, 1988). However, a single robust and barbed specimen, illustrated by Clark (1997: Plate VIII.12), was recovered from a nearby site on Takli Island (Schaaf, 2009).

Fish scaler-Two implements recovered from the Upper Midden locus have been tentatively identified as fish scalers (Hilton, 2000). Identification of these implements was based on a photograph and accompanying text from Northern Alaska that was published by Murdoch (1988: Figure 313). The fish scalers, made from land mammal bone, are between 9 and 10 cm in length (Hilton, 2000). Both specimens have edges that are worn smooth; however, the distal tips are more extensively worn (Hilton, 2000).

Lithic

Floats-One grooved pumice float was recovered from the Upper Midden locus at Mink Island (Figure 4.13). The pumice float was found in Level 3 of Excavation Area A, which dates to 535 cal. BP (Hilton, 2000). The pumice float is oval in cross section, measured 6.4x8.7x4.1 cm, and weighed 85 g (Hilton, 2000). The float had a pitted exterior that resembled a coarse igneous rock (Hilton, 2000). The grooved pumice float had a nearly 2 millimeter (mm) deep-

groove incised around the perimeter of the short axis to be used for lashing (Hilton, 2000). One portion of the float was stained a deep red color. More tests are needed to determine whether the stain represents a bloodstain or an unrelated taphonomic transformation (Hilton, 2000).

Figure 4.13. Pumice net float from Mink Island.

Notched stones-Notched stones first appear during the Early Kachemak phase (ca.3500 BP), and are common in North Pacific archaeological sites. These stones tend to be small (<10 cm) and flat with small notches chipped into the ends (Figure 4.14) (Hilton, 2000). Notched stones have been interpreted variously as net sinkers tied along the lower edge of fishing nets and nets used to procure birds and seals (Clark, 1974a; Davydov, 1977; Lisianskii, 1814). Large concentrations of notched stones in Kachemak tradition sites along some rivers, lends credence to the idea that they were used as net sinkers for salmon procurement.

Forty-six notched stones were recovered from widely distributed contexts at the Mink Island site, although a small, loosely associated group was recovered from level 12 (n=11) (Figure 4.14) (Hilton, 2000). The notched stones were created from a variety of raw materials including greywacke beach pebbles, basalt, granitic variations, andesite porphyry, and sandstone (Hilton, 2000). Five of the notched stones were created from cobble spalls, the remaining specimens were created from intact flat pebbles. Two of the notched stones were larger (363 g and 748 g) and more round than the rest of the collection (Figure 4.14; stone O), which weighed between 22 g and 128 g and averaged 68 g. The larger notched stones correspond with the Type 2 stones found in the Takli Island and Kukak Bay collections (Clark, 1977:162). The smaller notched stones correspond with the Type 1 sinkers found in the same collections (Figure 4.14; stones A-L) (Clark, 1977: 162). The notched stones ranged in length from 3.3 cm to 9.5 cm, and averaged 6.8 cm (Hilton, 2000). The notched stones recovered from levels 9-12 tend to be larger (averaging 76 g) than those recovered from levels 3-6 (averaging 44 g). A reduction in the size of notched stones is consistent with the shift from Norton/Kachemak to Thule traditions (Clark, 1977).

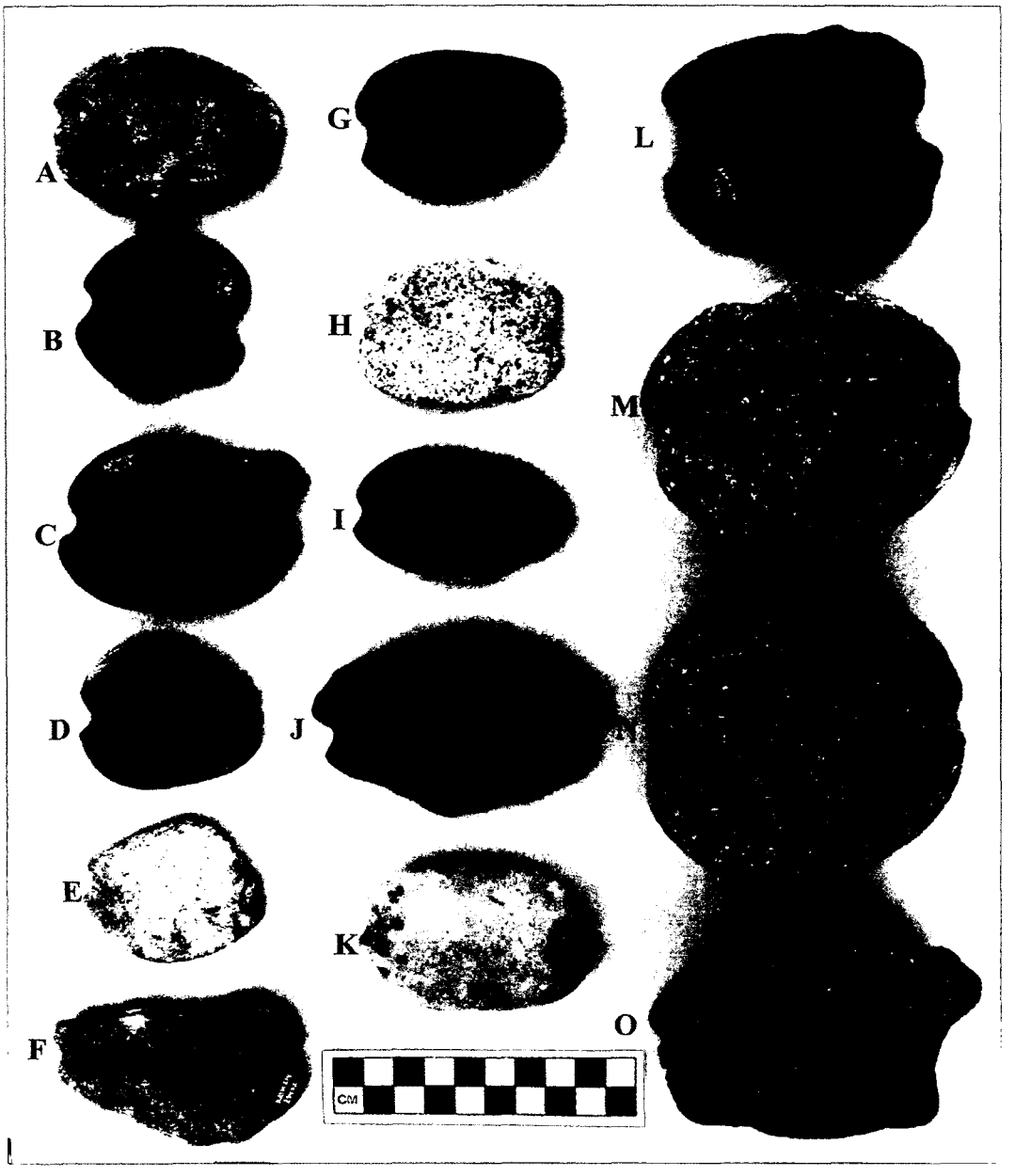


Figure 4.14. Fishing-related artifacts from Mink Island Upper Midden locus. A= notched stone, Excavation Area A, level 10; B= notched stone, Excavation Area A, level 12; C= notched stone, Excavation Area A, level 12; D= notched stone, Excavation Area A, level 4a; E= notched stone, Excavation Area A, level 3b; F= notched stone, Excavation Area A, level 12; G= notched stone, Excavation Area A, level 4h; H= notched stone, Excavation Area A, level 4a; I=notched stone, Excavation Area C, surface; J= notched stone, Excavation Area A, level 12; K= notched stone, Excavation Area A, level 5a; L= notched stone, Excavation Area A, level 10; M= grooved stone, Excavation Area A, level 10' N= grooved stone, Excavation Area C, level 5; O= grooved stone, Excavation Area A, level 6.

Grooved stones-Fishing-related grooved stones are similar in shape and function as notched stones; however, they differ in a few important ways. Most notably, grooved stones tend to be more rounded as compared to notched stones, and have grooves pecked around the perimeter rather than being notched on the ends. Grooved stones have variously been interpreted as fishing net weights and as line sinkers for deeps-sea fishing (Clark, 1977). See Figure 4.11 for an interpretation as to how grooved stones were used with composite fishhooks and a wooden spreader bar for deep-sea fishing.

Two fishing-related grooved stones were recovered from the Upper Midden locus at Mink Island (Figure 4.14; stones M and N) (Hilton, 2000). The oldest fishing-related grooved stone was recovered from level 12 in Excavation Area A, which has been dated to 1955 cal. BP (Hilton, 2000). This grooved stone is similar to one published by D. Clark (1997: Plate 7m), and has been referred to as a "plummet sinker of the sculptured variety." The groove is diagonally pecked around the neck of the pebble-sized stone, which would have caused it to hang offset from its attachment. The grooved pebble measured 2.9x4.8x2.3 cm and weighed 46 g (Hilton, 2000). The other grooved stone that resembles the plummet variety was recovered from Excavation Area C, which dated between 490 and 665 cal. BP (Hilton, 2000). This grooved stone was created from a smooth, nearly flat pebble that measured 3.7x5.0x1.5 cm and weighed 40 g (Hilton, 2000). The grooved stone did not appear to be finished; however, a knob was beginning to take shape on one end. It would not have been possible to affix a line to the grooved stone as found (Hilton, 2000).

Discussion

Because the analysis of fishing-related artifacts recovered from Mink Island is ongoing, the list presented above is incomplete. Therefore, interpretations of changing fishing strategies based on fishing-related artifactual data are not presently possible. Interpretations of fishing strategies, therefore, must be based primarily on fish faunal data (see Chapter 8). Because certain fishing-related artifacts (e.g. notched stones, ulus, and fishhooks) may be diagnostic to phases and traditions, their presence within an assemblage remains useful to the interpretation of Mink Island lifeways.

Conclusions

This chapter firmly places the Mink Island site within the regional cultural context. The regional history of archaeological exploration provides a description of the areas that have been surveyed and identifies those locations that warrant additional investigation. The cultural history section, which uses data obtained from archaeological explorations, identifies how prehistoric lifeways changed over time within the study area. The Mink Island site-specific data is used to determine where the Mink Island site fits within the regional pattern.

The Mink Island site generally conforms to the Shelikof Strait coast sub-regional cultural history sequence. However, the presence of the Paleoarctic tradition component at Mink Island is unique and presents an unparalleled opportunity to explore the extent of human occupation in the region. The absence of cultural materials associated with the Neoglacial period is also interesting and warrants further investigation. Additional archaeological explorations at Mink Island are needed to determine if the lack of cultural materials associated with the Neoglacial period are because of the excavation strategy employed or because the site was actually abandoned during that cold and stormy period. Analysis of fish remains recovered from the nearby Little Takli site (XMK-031) (e.g. Hood, in prep), which date to the Neoglacial period, may help to shed light on the interactions among humans and fishes during this cool and stormy period.

Chapter 5. Fish Bone Taphonomy: Zooarchaeological and Stable Isotopic Implications

Introduction

Taphonomy is the science of embedding or burial, the study of the transition, in all details, of animal organics from the biosphere into the lithosphere (Efremov, 1940). The goal of taphonomic research is to ascertain the difference between a recovered faunal assemblage (sample assemblage) and the community from which it came (living assemblage), or to remove its taphonomic overprint (Hill, 1979; Lyman, 1982, 1994). An unknown number of skeletal elements may be lost during each stage from a living assemblage to a sample assemblage; it is the taphonomists' goal to account for these processes (Ringrose, 1993).

To avoid biases associated with inter- and intra- taxa differences in preservation potential, it is essential to complete taphonomic analysis before measuring abundance of an archaeological faunal assemblage (Lyman, 1994). The purpose of this chapter is to describe the biostratinomic (cooking, weathering, gnawing, trampling, transportation, and abrasion) and diagenic (leaching, microbes, root etching, pH, turbation, wave action attrition, and compaction) agents that affect preservation and contamination potential of fish bones in coastal shell middens.

This chapter begins with a description of the chemical composition of bone, which focuses on the structural and chemical differences between mammals and fishes. The ways that biostratinomic and diagenic agents affect bone preservation are also covered. Again, these descriptions are focused on the impacts of taphonomic agents on fish bones. Concluding remarks describe the process of bone diagenesis within a coastal shell midden context.

Bone Structure

Bone is a highly specialized composite that is comprised of organic and mineral phases (Child, 1995a; Currey, 2002; Hanson and Buikstra, 1987; Linse, 1992). The mineral phase, which encompasses 70% of the bone composite, is a non-stoichiometric, carbonate-containing analog of hydroxyapatite (Posner, 1985) with the chemical composition of $Ca_{10}(PO_4)_6(OH)_2$ (Child,

1995b; Currey, 2002). The hydroxyapatite mineral phase contains calcium, phosphate, and hydroxyl ions (as indicated by the chemical formula), however, it also contains substantial quantities of carbonate and smaller quantities of potassium, sodium, magnesium, and pyrophosphate (not included in the chemical formula) (Armstrong and Singer, 1965; Misra, 1984). Strontium and lead, which are ingested from the diet, are also incorporated into the inorganic phase of bone (Child, 1995b).

The organic phase, which comprises the remaining 30% of the bone composite, consists of collagen, non-collagenous proteins, lipids, mucopolysaccharides, and other carbohydrates (Currey, 2002; Hanson and Buikstra, 1987; Triffitt, 1980). Type I collagen makes up the bulk of the organic phase of bone (Currey, 2002) and is comprised of two α1(I) chains and one α2(I) chain that combine to form a triple-helix (Veis and Sabsay, 1987). Non-collagenous proteins found in the organic phase of bone include: α-2HS-glycoprotein, albumin, osteonectin, and osteocalcin (Ingram *et al.*, 1993). The remaining 5-10% of the organic portion of bone consists of lipids, and various other mucopolysaccharides and carbohydrates (Child, 1995a). Although relatively little information concerning the nature of these lipids, mucopolysaccharides and carbohydrates may be found in the literature, there is some indication that these materials act as a glue that binds the inorganic and organic phases together (Hedges, 2003).

The mechanical integrity of a bone is largely determined by its bone volume density, or the porosity per unit volume of a bone (Burr, 1980). Bone consists of a combination of dense, compact bone and porous, cancellous bone (Currey, 2002; Hall, 2005). The bone volume density ratio of compact to cancellous bone depends on the structure and function of that particular bone (Romer and Parsons, 1977). Long bones, which support the weight of land mammals, typically consist of dense, compact bone in the diaphysis and at muscle attachment sites and mostly porous, cancellous bone in the epiphyseal ends. Cancellous bone consists of many individual struts, which provide additional strength while reducing weight. Because of its greater porosity, cancellous bone is weaker than compact bone (Burr, 1980; Hall, 2005). Bones that do not need to support the weight of the animal, such as the scapula, skull, rib, etc., tend to be less dense and are less resistant to compressive forces (Micozzi, 1991).

Along with bone volume density, the number, size, orientation, and the degree of crosslinking of collagen fibrils also influence bone strength (Burr, 1980; Hall, 2005). The

orientation of biostratinomic split-lines and weathering cracks often coincide with the orientation of collagen fibrils in the bone. Thus, the biostratinomic effects tend to be parallel to the long axis of a bone. Because of this connection, bone volume density must be considered in concert with the number, size, orientation, and degree of crosslinking of collagen fibrils to measure the strength of a specific bone (Lyman, 1994). Hydroxyapatite crystals provide rigidity and support (resistance to compressive forces), whereas collagen fibrils provide toughness, resiliency, and elasticity (resistance to tension forces) to the bone (Hildebrand, 1974; Johnson, 1985; Romer and Parsons, 1977).

Mammal versus Fish Bone

Fishes possess a distinct structural (mineralization, collagen fibril packing, and bone volume density) and chemical (amino acid sequence, lipid content, protein content) composition than mammal bones (Szpak, 2011). These structural and chemical differences result in differing preservation and contamination potential. Therefore, it is essential to consider the effects of differential preservation when interpreting abundance of multi-class (e.g. mammals and fishes) faunal assemblages.

Mammal bones are cellular (have osteocytes) and fish bones are cellular or acellular (without osteocytes) depending on the taxon (Moss, 1961; Nicholson, 1996a; Witten and Huysseune, 2009). Most fish taxa possess acellular bones, however fishes from the order Clupeiformes (herring and anchovies), Elopomorpha (eels, bonefish, and tarpons), and Osteoglossomorpha (bony tongues and mooneyes) possess cellular bones (Fleming, 1967; Parenti, 1986). Cellular bone growth is dependent on the interaction between bone-lining cells, osteoblasts, osteocytes, and osteoclasts (Currey, 2002). Whereas acellular bone does not depend on bone cells; new bone is laid down at the edges of the bone in incremental structures, similar to that seen with shellfish (Moss, 1961; Nicholson, 1996a).

Diagenic agents affect cellular bones differently than acellular bones (Nicholson, 1996a). Cellular bones are attacked on the periosteal surface by fungi and bacteria, which breach the bone cortex through canaliculi (microscopic canals) (Currey, 2002). Whereas acellular bones are attacked at the edges, where the youngest bone cracks and crumbles without the associated

pitting and channeling (Nicholson, 1996a). Because of these structural differences, fish taxa with cellular bones (i.e. herring) have more access points (canaliculi) and, as a result, are more susceptible to the effects of microbial diagenesis (Szpak, 2011).

Besides the cellular/acellular differences, mammal bones and fish bones differ in several other important ways. Although the arrangement of the hydroxyapatite and collagen portions of mammal and fish bones appears to be similar (Bigp *et al.*, 2000; Jackson *et al.*, 1978; Kim *et al.*, 1995), their ratios are distinct (Moss, 1961, 1963). Fish bones have a larger proportion of uncalcified collagen bundles as compared to mammal bones (Moss, 1961, 1963; Neuman and Mulryan, 1968). Additionally, the collagen fibrils in fish bones tend to be less densely packed than mammal bones (Lee and Glimcher, 1991). When combined, lower mineralization and less densely packed collagen fibrils cause fish bones to have lowered bone volume density values (Butler and Chatters, 1994; Smith, 2008). Less-dense bones are more susceptible to breakage and degradation within burial environments (Nicholson, 1996a). Lowered mineralization and loosely packed collagen fibrils also cause fish bones to be more susceptible to microbial action. Bacterial enzymes from the burial environment, which tend to be large, are able to penetrate the loosely packed fish collagen fibrils to degrade them much easier than mammal collagen (Szpak, 2011).

In addition to having structural differences, fish and mammal bones also have different collagen amino acid compositions (Avena-Bustillos *et al.*, 2006; Gudmundsson, 2002). Typical fish collagen has lower percentages of proline and hydroxyproline, and higher percentages of glycine and serine (Eastoe, 1967; Szpak, 2011). Differences in the amino acid composition cause fish bone collagen atomic carbon to nitrogen ratios (atomic C: N), percent carbon by weight values (%C), and percent nitrogen by weight values (%N) to be lower as compared to their mammalian counterparts (Arnesen and Gildberg, 2006; Szpak, 2011). Intra-taxa variability of the amino acid composition of fish bone collagen also exists; warm-water-adapted taxa (tropical and subtropical) have higher concentrations of hydroxyproline than cold-water-adapted taxa (polar and temperate) (Regenstein and Zhou, 2007). These intra-taxa differences in hydroxyproline content, however, are not large enough to alter atomic C: N, %C, and %N values significantly (Szpak, 2011).

Fish collagen's overall lower levels of proline and hydroxyproline (as compared to mammal collagen) result in weaker covalent and noncovalent bonds (Regenstein and Zhou, 2007). Weaker bonds cause fish bones to be more prone to chemical leaching in burial environments and to have a lower melting point in response to heat (Szpak, 2011). Therefore, fish bones are more susceptible than mammal bones to degradation by diagenic agents (Szpak, 2011). Cold-water-adapted fish (polar, temperate) bones have the lowest hydroxyproline levels, and therefore are even more susceptible than warm-water-adapted fish bones to degradation by diagenic agents (Szpak, 2011).

Another inter-class distinction that affects preservation potential is that fish bones contain much higher amounts of lipids (triglycerides, cholesterol and phospholipids) than mammal bones (with the exception of some marine mammals) (Herring, 1972; Phleger *et al.*, 1976, 1989, 1995; Tont *et al.*, 1977). Higher lipid content of bones deposited in burial environments results in increased putrefaction, which produces increased levels of organic acids as byproducts (Witten and Huysseune, 2009). Organic acids causes the bone collagen component to hydrolyze and swell (Collins *et al.*, 2002), which causes fish bones to degrade in burial environments at much faster rates than seen with mammal bones (Collins *et al.*, 2002).

Inter-class distinctions in bone protein levels, as indicated by bulk bone percent nitrogen content, also affects preservation potential within burial environments (Petchey and Higham, 2000). Those bones with higher protein content tend to survive the effects of biostratinomic and diagenic agents better than those bones with lower protein content (Petchey and Higham, 2000). Mammal bones begin with more protein; therefore, with all other things being equal, mammal bones exhibit higher survival rates than fish bones (Stafford *et al.*, 1988).

Biostratinomic Agents

Introduction

Biostratinomic agents affect bone survival before their final burial in an archaeological context and may alter the deposited and recovered bone assemblage (Nicholson, 1996a, 1998; Richter, 1986; Shipman *et al.*, 1984; Steiner *et al.*, 1995). Biostratinomically altered bones are

less able to withstand the effects of diagenic agents, and therefore, are often underrepresented in the archaeological record. The following biostratinomic agents are described in this section: Cooking/burning, weathering, carnivore and rodent action, trampling, transportation, and abrasion.

Cooking/Burning Bones

Heat-induced morphological changes occur when bones are cooked (boiled, roasted, or baked) or burned (cooking, fuel for fires, cremation, and brush or forest fires) (Lyman, 1994; McCutcheon, 1992; Richter, 1986; Shipman *et al.*, 1984). These morphological changes affect the bone's preservation potential, leaving them more vulnerable to the effects of other biostratinomic and diagenic agents (Lyman, 1994; McCutcheon, 1992; Richter, 1986; Shipman *et al.*, 1984). Heating causes physical and chemical alterations within the bone (Armstrong and Singer, 1965; Bonucci and Graziani, 1975; Brain, 1981; Johnson, 1989; Kizely, 1973; McCutcheon, 1992; Shipman *et al.*, 1984; Von Endt and Ortner, 1984). These alterations are irreversible and are directly related to the specific temperature to which the bone was heated (McCutcheon, 1992).

Cooking/burning affects the organic (collagen) and mineral (hydroxyapatite) portions of the bone at the same time (Johnson, 1989; Shipman *et al.*, 1984). Heating causes the collagen fibrils to melt (Szpak, 2011), the hydroxyapatite to melt, and the mineral content to recrystallize (Shipman *et al.*, 1984). Melted collagen fibrils are more susceptible to destruction by bacterial enzymes (Marchiafava *et al.*, 1974; Richter, 1986). Cooked/burned bone is also more vulnerable to dissolution in acidic burial contexts (Knight, 1985). Additionally, bones that are heated between 300°C and 400°C contain more carbon or "organic char" (Brain and Sillen, 1988: 464), which affects biogeochemical values (^{14}C, $\delta^{15}N$, $\delta^{13}C$). Organic char causes the atomic carbon to nitrogen ratio (atomic C: N) to increase to levels outside the acceptable range (see Van Klinken, 1999), which has implications for stable isotopic research (Ambrose, 1993).

Weathering

Weathering is part of the natural nutrient recycling process that decomposes and destroys bones (Behrensmeyer, 1978). Bones become weathered as chemical and physical agents separate and destroy the bone's original organic and inorganic portions (Behrensmeyer, 1978). The alternating effects of freezing and thawing, wetting and drying, and heating and cooling break down bones left on the surface that are not protected by burial sediments (Behrensmeyer, 1978; Miller, 1975; Shipman, 1981).

Taxa- and skeletal-element specific differences in size, shape, density, and composition causes bones to weather at different rates despite being found in the same depositional environment (Behrensmeyer, 1978, 1982; Butler and Chatters, 1994; Gifford, 1981; Nicholson, 1992a, 1992b). Mammal bones, which tend to be larger, denser, and possess more densely packed collagen fibrils as compared to fish bones, generally withstand weathering better than fishes (Nicholson, 1996a; Petchey and Higham, 2000). Additionally, fish bones that are larger, more reinforced, and more dense (e.g. dentary, premaxilla, quadrate, vertebrae) weather more slowly than fish bones that are smaller, less reinforced, and less dense (e.g. opercular, interopercular, cleithrum, parasphenoid, etc.) (Nicholson, 1992b).

Factors such as depositional micro- and macroenvironmental conditions and exposure duration also affect weathering rates (Behrensmeyer, 1978; Gifford, 1981; Lyman, 1994; Nicholson, 1992a). Bones that are surrounded by sparse vegetation weather more quickly than bones surrounded by dense vegetation (Behrensmeyer, 1978). Bones that are exposed to vast swings in temperature or moisture weather more quickly than bones exposed to constant temperature or moisture (Behrensmeyer, 1978; Brain, 1967; Cook, 1986; Miller, 1975). Additionally, bones that have been exposed to the depositional environment for longer periods (exposure duration) tend to be more weathered than bones that have been exposed for shorter periods (Lyman, 1994).

The accumulation history also affects the weathering rate as it is a measure of how bones become deposited in a specific location (e.g. shell midden, riverbank, etc.). Bones (e.g. carcasses) that were accumulated en mass (e.g. shell midden) tend to weather more slowly than bones that were widely dispersed (e.g. riverbank) (Todd, 1983a, 1983b). Similarly, bones found

on the top of a pile of closely spaced carcasses (e.g. shell midden) will be more weathered than those found on the bottom of a pile (Saunders, 1977).

Carnivore and Rodent Biostratinomic Agents

Carnivores and rodents act as biostratinomic agents by chewing, gnawing, sucking, eating, trampling, and transporting carcasses/skeletal remains (Lyman, 1994; Shipman, 1981). Biostratinomic damage caused by carnivore and rodent action affects the skeleton's ability to withstand degradation by diagenic agents (Shipman, 1981). Carnivore and rodent action compromises the integrity of the outer cortical bone layer (Lyman, 1994), which provides microbes and other diagenic agents access to the interior portions of the bone where it is degraded from the inside out (Shipman, 1981).

Although the effects of chewing/gnawing on mammal bones has been extensively researched (e.g. Haynes, 1980; Lyman, 1994, 2008; Maguire *et al.*, 1980; Shipman, 1981), comparatively little research has been conducted for fish bones (e.g. Nicholson, 1992b; Wheeler and Jones, 1989). Carnivores typically chew or gnaw a mammal long bone by removing epiphyseal ends and breaking the diaphysis into long-longitudinally aligned splinters to get at bone marrow (Johnson, 1985). Because fish bones are differently shaped and do not contain the same type and quantity of bone marrow (Witten and Huysseune, 2009), they typically do not exhibit the same marrow-extraction breakage patterns (Lyman, 1994). Similarly, fish bones tend to be easier to puncture, break, and consume than mammal bones, therefore, fish bones will not have the characteristic gnawing marks. If a fish bone is chewed by a rodent or carnivore without being ingested, it will most likely not be able to withstand destruction by diagenic destruction and be absent from the archaeological assemblage (Nicholson, 1992b, 1996a, 1998; Petchey and Higham, 2000).

Jones (1986) fed entire herring, haddock, and mackerel to a pig, a dog, and a human and collected the feces to determine which bony parts survived passage through the digestive tract. The bones that survived are those that are regularly recovered from archaeological contexts. Otoliths (ear bones) showed signs of digestion; polishing, smoothing, and shortening (one otolith was 2 mm shorter) (Jones, 1986). Some vertebrae survived although they were crushed

(Jones, 1986). Other skeletal elements passed through the digestive system apparently unharmed (Jones, 1986). Of those, skeletal elements with higher bone volume density (e.g. dentary, premaxilla, maxilla, palatine, quadrate, otolith, and vertebrae) survived best (Jones, 1986; Nicholson, 1992a). Although a single opercle and cleithrum survived despite having lower bone volume density, their survival may be because they are thin, flat and easily manipulated when wet (Jones, 1986). Jones's analysis found that fewer than 10% of the fish bones ingested by the pig, dog, and human survived passage through the digestive system (Jones, 1986). Care must be taken when assessing the relative importance of different fish taxa, even when a small sieve size has been used. Where scavengers have access to fish waste deposits, the sample size will be reduced and biased (Jones, 1986)

Trampling

Trampling occurs when humans and other animals (especially hooved animals) step on bones, marking (scratching), fracturing (crushing), and displacing (spatially) them (Lyman, 1994). When a hooved animal steps on a bone, it may leave a scratch mark. If the animal produces a significant amount of force, the bone may fracture. Bones that are less dense and lack reinforcement are more susceptible to fracturing. Trampling may fracture bones so intensely that they become unidentifiable, and thus, analytically absent from the archaeological record (Haynes, 1991; Lyman and O'Brien, 1987). Bone shape affects preservation potential; spherical-shaped bones resist fracture better than plate-shaped or cylinder-shaped bones (Yellen, 1991). The weathering stage, may also affect a bone's preservation potential. Fresh or green bones are more durable than weathered bones and thus, resist trampling (Olsen and Shipman, 1988). Although, given enough force, green bones may also be fractured by trampling (Lyman, 1994).

The effects of trampling on fish bones has received little attention other than the work of Rebecca Nicholson (1992b) who compared trampling effects on fish, mice, and frogs. Her research determined that fish bones were affected by trampling (became more fragmented) more than mice or frogs, and that size was an important factor (Nicholson, 1992b). Larger fishes (e.g. Atlantic cod) resisted trampling and fragmentation much better than smaller fishes (e.g. haddock and herring) (Nicholson, 1992b). She also found that spherical and short (vertebrae)

fish bones were found more frequently at depth as compared to every other bone shape (Nicholson, 1992b). Vertical movement is dependent on the sediment compactness, intensity of the trampling, the extent to which the bones were already buried, and the size and shape of the bones (Lyman, 1994).

Transportation

When a complete or partial carcass enters a depositional environment (shell midden, etc.), it becomes available to carnivores, scavengers, and rodents. The skeletal remains may be moved by dragging, ingestion, and trampling. Dragging leads to disarticulation and scattering of individual carcass segments or skeletal elements (Lyman, 1994). The segments are sometimes held together by connective tissue (such as a complete limb or a backbone) and other times are completely disarticulated (Hill, 1979). Scattering often moves segments or skeletal elements large distances from the original depositional location. The degree of scattering depends on the length of time between deposition and burial (Hill, 1979). Bones of carcasses that are buried immediately tend to stay articulated (Lyman, 1994).

Research has focused on the effects of transportation by carnivores, scavengers, and rodents on mammal bones (Behrensmeyer *et al.*, 1986; Hill, 1979; Lyman, 1994). Because fish carcasses are typically smaller and are more easily transported, it is plausible that they may have been more scattered than other animal classes. It also seems plausible that they would have been ingested, leaving little trace of their existence (and what trace was left would have been removed from the original depositional environment).

Abrasion

Abrasion occurs when an agent erodes a bone surface using force (Bromage, 1984). Abrasion is most often caused by the impact of sedimentary particles, but may have other causes (Shipman and Rose, 1988). Eolian transport, fluvial transport, trampling, human tool making and use, cooking, and wave action are abrasive agents (Brain, 1967; Martill, 1991; Olsen and Shipman, 1988; Sadek-Kooros, 1975; Shipman and Rose, 1988; White, 1992).

The effects of abrasion have been extensively studied on mammal bones; however, little is known about the effects on fish bones with one exception. Rebecca Nicholson (1992b) conducted an actualistic experiment where fish, frogs, and mice were abraded to assess effects. She discovered that frogs were much more resistant to abrasion than mice and fish. The fish bones were not as straight forward: plaice bones were much more resistant to abrasion than similarly sized herring and haddock bones. She discovered that bone loss correlated with bone shape; more robust bones of the jaw (dentary, premaxilla, quadrate) and spherical bones (vertebrae) were favored over flat and irregular bones (cleithrum, parasphenoid, opercular, etc.) (Nicholson, 1992b). Nicholson (1992b) also determined that salmon bones were destroyed faster than other bones because of calcium depletion associated with spawning. Because of Nicholson's (1992b) research, it may be concluded that those skeletal elements that are large, reinforced (jaw and vertebrae), and robust may be expected to resist abrasion better than those that lack those characteristics.

Diagenic Agents

Introduction

Bone diagenesis occurs after animal remains are buried within archaeological sediments (Lyman, 1994). Intrinsic (bone size, porosity, chemical structure, and molecular composition) and extrinsic (pH, temperature, moisture content, and microbial action) factors control the rate at which a bone undergoes diagenesis (Child, 1995a; Hedges, 2002; Linse, 1992; Lyman, 1994; Von Endt and Ortner, 1984). Bone diagenesis occurs at three levels: 1) within the bone, 2) within the bone's pore cavities, and 3) within the sediment surrounding the bone (Martill, 1991). The nature and type of diagenic alteration differs within each level: mineral ions substitute apatite ions within the First Level; diagenic minerals fill pore spaces and contaminate bones within the Second Level; and ions and minerals leached from bones, shells, and other organic materials from the burial context saturate and contaminate the sediment in the Third Level (Martill, 1991).

Diagenesis may be divided into syndiagenesis, andiagenesis, and epidiagenesis (Rolfe and Brett, 1969). Syndiagenesis involves microbial degradation of animal soft tissues within shallow sediments. Andiagenesis involves compaction and cementation of animal remains deep within the burial context. Epidiagenesis involves the complete disappearance of the buried animal remains (Rolfe and Brett, 1969). Zooarchaeologists typically do not focus on epidiagenesis because the bone structure is lost during that phase (Lyman, 1994; Moss, 1984).

Bone volume density affects the rate in which a bone undergoes diagenic chemical alteration. Bones that are more dense (low porosity) are better able to withstand the effects of chemical diagenesis (e.g. pH, ion exchange, etc.) than bones that are less dense (high porosity) (Sillen, 1989). Porous bones more readily exchange ions from the surrounding burial sediment because the pore spaces act like a sponge and absorb dissolved contaminants (Hanson and Buikstra, 1987; Linse, 1992). Dense bones lack pore spaces, and therefore, do not readily exchange ions with the burial sediment (Sillen, 1989).

The burial environment temperature also affects the rate at which a bone undergoes diagenic alteration. Bone preservation may be different in desert, tropical, temperate, and arctic environments (Lyman, 1994). Bone preservation is typically better in arctic and desert environments because these locations are consistently frozen (arctic) or dry (desert) (Von Endt and Ortner, 1984). Bone preservation is not as good in temperate and tropical environments because these locations fluctuate between freezing and thawing (temperate) and wetting and drying (tropical). Chemical reaction rates double for every 10°C increase in temperature (Von Endt and Ortner, 1984). Temperature also influences microbial (bacteria, fungi) action because they typically prefer warm and moist conditions (Sillen, 1989).

The specific properties of the burial context (e.g. chemistry, acidity, moisture content, permeability, etc.) also affects the bone diagenesis rate (Tuross *et al.*, 1989). Bones deposited in contexts with extreme pH values are affected by diagenesis more quickly than bones deposited in more-neutral depositional contexts (Linse, 1992). Additionally, bones deposited in consistently wet or dry environments are better preserved than bones deposited in environments that fluctuate between wet and dry environments (promotes leaching) (Von Endt and Ortner, 1984). Ions leach from bones during wet intervals, and contaminants from the

burial matrix absorb into pore spaces during dry intervals (Linse, 1992; Sillen, 1989; Von Endt and Ortner, 1984).

Finally, the burial duration also affects the rate of bone diagenesis (Lyman, 1994, 2008). While the link between burial duration and bone diagenesis may appear to be linear, it is not. Factors such as whether an animal was buried with intact soft tissue, or was weathered or cooked before burial affects diagenesis rates (Sillen, 1989).

Leaching and Enrichment

During fossilization, bones become altered in three significant ways: organic structures (collagen, etc.) disappear, organic matter is replaced by soluble material from the water found in the burial matrix, and stoichiometric hydroxyapatite crystals replace non-stoichiometric crystals and infiltrate the open pore spaces left by the disappearing organic structures (Ascenzi, 1969). Bones become leached of ions (degraded) and enriched (contaminated) when exposed to rainwater or groundwater. Leaching occurs when soluble materials are removed from the bone after water exposure. Enrichment occurs when soluble matter is absorbed into vacant pore spaces when the burial context dries. Enrichment may also occur via encrustation where soluble salts (e.g. calcium carbonate, etc.), derived from the sediment, are transported by groundwater and precipitate on the bone surface when the burial context dries (Ascenzi, 1969; Lyman, 1994). Encrustation usually only occurs in dry environments where there is insufficient moisture to flush salts from the burial context (Lyman, 1994). Buried bones will be transformed by reduction and enrichment until equilibrium is established between the bone and the burial context (Whitmer *et al.*, 1989).

Biological Syndiagenic Agents

Microbes (Bacteria, Fungi)

Microbial (bacterial, fungal) diagenesis occurs rapidly after death (fewer than 500 years) (Bell *et al.*, 1996; Hedges, 2002; Yoshino *et al.*, 1991) and is one of the most common

mechanisms for bone diagenesis in archaeological contexts (Child, 1995b; Collins *et al.*, 2002). Microbial attack causes the mineral portion of bones to become more porous while simultaneously degrading and contaminating the organic portion (Alexander, 1965; Child, 1995a, 1995b; Child *et al.*, 1993a, 1993b; Colson *et al.*, 1997; Jans *et al.*, 2004; Marchiafava *et al.*, 1974; Nielsen-Marsh and Hedges, 1999). Microbes from the soil (bacteria, fungi) or from the gut of the animal (bacteria) simultaneously degrade bones via hydrolysis (soil) or autolysis (gut). Hydrolysis may occur in oxygen rich or oxygen-depleted environments in the soil, whereas autolysis occurs in oxygen-depleted environment of the gut (Child, 1995a).

The composition and number of soil microbes (bacteria and fungi) is dependent on soil pH, oxygen ratio, temperature, and moisture content (Child, 1995a; Collins *et al.*, 2002; Marchiafava *et al.*, 1974). Soil microbes thrive in near-neutral environments that are well aerated, warm and moist; they do not thrive in cold and dry environments that are extremely acidic or alkaline (Child, 1995b; Child *et al.*, 1993b; Teuscher and Adler, 1960). Microbial activity is also low in closed environments, and in those environments that contain competing microbial communities and inhibitory substances (Child, 1995a; Collins *et al.*, 1995). Closed environments, that experience little or no leaching, promote bone preservation because ions are not exchanged between the bone and the burial sediments (Child, 1995a). Where competing microbes coexist, bone preservation is better because the competing microbes focus their energy on attacking each other rather than attacking bones (Teuscher and Adler, 1960). Copper, mercury, lead, and vegetable tannates also repel microbes, and thus, bone preservation is promoted in their presence (Janaway, 1987).

Animals that are buried with intact viscera will undergo autolysis (self-destruction). Autolysis is a quick process (beginning as soon as 10 seconds after death) where upon cell death, proteinase and deoxyribonuclease enzymes (DNase) are released within the gut (Child, 1995a; Garland *et al.*, 1988; Trump *et al.*, 1981). These enzymes splice DNA, and speed up soft tissue destruction and cause putrefaction of animal viscera (Child, 1995a). Autolysis (putrefaction) occurs in oxygen free environments, and is self-limiting; autolysis will stop when organic material is metabolized or when conditions become too dry or cold (Janaway, 1987; Nicholson, 1996a).

While animals are attacked from the inside via autolysis (gut bacteria), they are also attacked from the outside via hydrolysis (soil bacteria and fungi). Aerobic microbes (fungi and bacteria that require oxygen to metabolize bone proteins) begin by degrading an animal's soft tissues (e.g. muscles, skin, tendons, ligaments, etc.), which produces organic and carbonic acids (Nicholson, 1996a; Nielsen-Marsh and Hedges, 2000). The organic and carbonic acids dissolve the mineral portion of the bone, and provide access for microbes to degrade the organic portion of the bone (Hedges and Millard, 1995). At that point, aerobic fungi and bacteria degrade the organic portion of bone until the rate of oxygen consumption exceeds the rate of oxygen diffusion into the burial environment. Then, aerobic microbes stop growing and facultatively anaerobic (bacteria that can function with or without oxygen) and anaerobic (bacteria that function without oxygen) microbes take over and further degrade the organic portion of the bone (Child, 1995a).

If defleshed bones are deposited in near-neutral pH conditions, microbial action typically takes another pathway. The diagenesis of defleshed bones does not produce organic or carbonic acids, which allows near-neutral pH conditions to persist (Child, 1995b; Smith *et al.*, 2007). Under these conditions, microbially-mediated dissolution may occur, in a process known as microscopic focal destruction (MFD) (Hackett, 1981). With MFD, microbes remove small, discrete portions of the mineral phase that tend to follow natural spaces (e.g. nerve lacunae and blood vessels) in attempts to reach the organic phase of the bone (Grupe and Pipenbrink, 1988; Lynch and Poole, 1979). Bacteria use proteolytic enzymes to penetrate the mineral phase, whereas fungal hyphae use force with little enzymatic softening to accomplish the same task (Swift *et al.*, 1979).

Regardless of how microbes gain access to the organic phase (MFD or chemical dissolution of the mineral phase), diagenesis occurs in the same manner (Child, 1995a). Microbial destruction of the organic phase occurs when proteolytic enzymes, also known as proteases, gain access to the bone. Those proteases that focus on breaking down the triple-helical structure of collagen into smaller polypeptide fragments (chains of amino acids) are called collagenases. Collagenases use hydrolysis (hydro=water, lysis=to destroy) to break bonds between specific amino acids. Those bonds that contain aspartic acid, serine and threonine residues are cleaved first and bonds that contain valine and leucine are cleaved last (Bada,

1991). The polypeptide fragments are then broken down into individual amino acids by other proteases (Child, 1995a; Wyckoff, 1972). Some, but not all, amino acids may be degraded further via decarboxylation, deamination, or dehydration (Bada, 1991). In archaeological soils, those amino acids that contain the most carbon (tyrosine, thyamine, histidine, and isoleucine) are lost first, whereas those containing the least amount of carbon (alanine and glycine) are lost last (Grupe, 1995).

In addition to degrading the organic portion during hydrolysis, microbes also contaminate the bone by depositing H_2O, and other waste products (as the result of metabolic action) within the bone structure. These waste products take the form of individual amino acids that were not originally part of animal's bones (Child, 1995a). Therefore, microbial action simultaneously degrades and contaminates bones, thus obscuring chemical signatures. Care must be taken to account for diagenesis and to remove contaminants before conducting biogeochemical analysis ($\delta^{13}C$, $\delta^{15}N$, ^{14}C) so that values are not skewed by preservation and contamination biases (Ambrose, 1990, 1993; Ambrose and Krigbaum, 2003; Hedges, 2002; van Klinken, 1999).

Bones that have been attacked by bacteria may also be secondarily attacked by saprophytic soil fungi (Marchiafava *et al.*, 1974; Nicholson, 1996a). Many saprophytic fungi are unable to digest intact bone collagen and require pre-digestion by collagenase-producing bacteria (Child *et al.*, 1993a). Heat-induced morphological changes may also degrade bone collagen enough for saprophytic fungi to gain access to digest bone (Child *et al.*, 1993a). Saprophytic fungi are common within the soil humus and attack bones if they are deposited in an oxygen-rich environment with at least a 20% humidity (Carlile *et al.*, 2001). Fungi are after the bone's organic phase and follow the same pathways (MFD, chemical dissolution of mineral phase) to get through the mineral phase (Swift, *et al.* 1979). Fungal attack may occur at any time from when the bone is deposited in the archaeological context until it is excavated. Therefore, the type of microbial attack (bacterial, fungal) will be determined by biostratinomic factors such as whether the animal was gutted, butchered, dismembered, and cooked before burial; as well as by moisture, temperature, vegetable tannate content, and oxygen levels of the surrounding environment (Child, 1995a; Jans *et al.*, 2004).

Microbes attack mammal bones and fish bones via the same process; the mineral phase is removed via chemical dissolution or MFD and the collagen portion is broken down into polypeptide fragments and then into free amino acids (Child, 1995a). Because fish bones are thinner, smaller, less dense, and have more widely spaced collagen fibrils than mammal bones, microbes degrade fish bones more quickly than mammal bones (Eastoe, 1956; Tristram and Smith, 1963; Witten and Huysseune, 2009).

Root Etching

Bone surfaces recovered from archaeological contexts often have "dendritic patterns of shallow grooves" etched into them (Behrensmeyer, 1978: 154). These etched patterns are either marks left by the dissolution by humic acids associated with the growth and decay of roots (Behrensmeyer, 1978) or marks left by organic acids secreted by fungi associated with decomposing roots (e.g. Morlan, 1980; Grayson, 1978). Regardless of the source (roots or fungi) or type of acid (humic or organic), the results are the same; root shapes become etched into bone surfaces (Behrensmeyer, 1978; Grayson, 1978; Lyman, 1994; Morlan, 1980). The humic or organic acid dissolves a portion of the bone surface, producing a groove in which the root or rootlet resides (Morlan, 1980).

Root etching may occur after burial (syndiagenesis) or before burial (biostratinomy). Mosses and lichens sometimes grow on bones and etch them on the surface before their final burial (Lyman, 1994). Bones that are etched by lichens indicate that the bone spent time exposed without being disturbed (Cook, 1986). Once a bone is buried, humic acids from roots and other organic acids from fungi may etch it.

Although the effects of root etching have been examined on mammal bones, the effect on fish bones has not been addressed. Because root etching affects the bone surface, there should be little difference between mammal and fish bones. One exception may be that fish bones have a thinner cortex layer than mammals (Witten and Huysseune, 2009), allowing roots to penetrate it more easily. Therefore, root etching may be responsible for a higher percentage of bone breakage among fish bones compared to mammal bones.

Chemical Syndiagenic Agents

Soil pH

The acidity or alkalinity (pH) of the burial environment also affects bone preservation during the syndiagenic phase (Gordon and Buikstra, 1981; Linse, 1992; White and Hannus, 1983). Bones will be differently preserved in depositional environments that range from alkaline to neutral to acidic (Linse, 1992). Because bone preservation in shell midden contexts is the focus of this dissertation, the effects of alkaline conditions on bones is the focus of this section.

Archaeologists have traditionally argued that bones are preserved under alkaline conditions and decompose under acidic conditions (Gilbert, 1977). While the mineral and organic phases decompose in acidic environments, those same phases are not always preserved in alkaline environments. The mineral phase of bone becomes soluble and decomposes under highly alkaline environments, but the organic phase is preserved under the same conditions (Linse, 1992). Therefore, both acid and alkaline environmental conditions influence preservation of archaeological bone.

Acidity is influenced by temperature, moisture, oxygen, calcium, and phosphorus content of the bone and surrounding burial environment (Person *et al.*, 1996; White and Hannus, 1983). The temperature affects the amount of water available in the burial environment, and water and oxygen are necessary for chemical activity to transpire (Hanson and Buikstra, 1987; Whitmer *et al.*, 1989). Calcium and phosphorus content alters the pH of burial environment; large amounts create an alkaline environment (e.g. shell middens) whereas smaller amounts are associated with acidic environments (Moss, 1984; White and Hannus, 1983).

The general sequence of bone diagenesis was outlined by White and Hannus (1983:321-322). Diagenesis begins when humus, microorganisms, water, and oxygen combine to break down tissue and collagen. The decay of the tissue and collagen produces organic and carbonic acids. The acids react with the bone exterior where the hydroxyapatite is most dense. The soluble bone mineral then exchanges calcium and phosphate ions with the surrounding

sediments to attain equilibrium. The chemical changes that a bone undergoes during the equilibrium process are dictated by the availability of ions in the solution within a burial environment. The available ions in the solution, in turn, are dictated by the hydrogen ion activity; and the hydrogen ion activity is dictated by the pH of the surrounding sediments.

In acidic environments, hydroxyapatite reacts (chemically) with carbon dioxide (CO_2), bicarbonate (HCO_3^-), and hydrogen ions (H^+), which leaches ions from the bone. In alkaline environments, calcium from the burial matrix may replace ions that are leached from the hydroxyapatite in the bone, which impedes the dissolution of the bone (Lambert *et al.*, 1985). Therefore, diagenesis of the hydroxyapatite portion of the bone is more pronounced in acidic environments compared to alkaline environments, although not absent (Linse, 1992).

Biological/Physical Andiagenic Agents

Turbation Processes

Post-occupational andiagenic disturbance of archaeological deposits is a regularly occurring phenomenon that alters the archaeological record. Archaeological deposits may be moved upwards and downwards by the burrowing action of rodents, ants, and earthworms (faunalturbation). Plant and tree roots (floralturbation) may move deposits downwards when roots are growing and then upwards when roots are forcefully ripped out as when a tree blows over. Freezing and thawing of the archaeological deposit (cryoturbation) may cause frost heaves, frost cracking, ice wedges, and sand wedges to develop; which may result in mass displacement, and sorting of the deposit. Gravity (graviturbation) in the form of solifluction, creep, subsidence, mudflows, earthflows, avalanches, and landslides, may cause deposits to move in all directions. The swelling and shrinking of clays (argilliturbation); the action of gas, air, and wind (aeroturbation); the movement of water (aquaturbation); the growth and wasting of salt (crystalturbation); and earthquakes (seismiturbation) may also move deposits in all directions. Finally, humans may move deposits downwards and laterally when plowing fields, or in all directions when excavating archaeological deposits (Lyman, 1994; Stein, 1983; Wood and Johnson, 1978).

Some turbation processes disturb archaeological deposits more extensively than others do. For instance, one would not expect to encounter the effects of cryoturbation in equatorial regions, aquaturbation in dry or protected areas (e.g. caves), argilliturbation in sandy areas, crystalturbation in freshwater locations, or seismiturbation in non-seismically active regions. Rodent and earthworm activity are particularly destructive, moving sediments upwards and downwards, which obscures the original stratigraphy. Earthworms thrive in shell midden contexts and evidence of their action is often overlooked (Stein, 1983).

Perhaps the most destructive turbation process is crystalturbation, where the growth and wasting of salts move archaeological deposits. Salt enters a shell midden when saltwater comes in contact the archaeological deposit. The saltwater is transferred through the deposit by wave action and by being absorbed through the matrix to fill empty pore spaces. As the lower portions are in contact with the saltwater more often than upper portions, the lower portions tend to be more impacted by crystalturbation. Once introduced into the shell midden, salt crystals form within the pore structure of a bone, causing the bone to crack (Tucker, 1991). Because a shell midden often fluctuates between wet and dry conditions, bones are affected by crystalturbation repeatedly. Given enough time, crystalturbation alone may cause fish bones to become so fragmented that they become unidentifiable, and thus analytically absent (Lyman and O'Brien, 1987).

Physical Andiagenic Agents

Wave Action Attrition

In coastal settings, wave action attrition is an andiagenic abrasive agent that grinds and polishes bones and shells in lower portions of middens (Martill, 1991; Stein, 1992a). Moving particles associated with nearshore wave, current or tidal action abrade bone and shell (Martill, 1991). Fine surface ornamentation or bony processes are the first to be abraded, eventually all ornamentation and processes become completely obliterated (Stein, 1992a).

Compaction

Compaction is a common andiagenic feature that alters the original size and shape of bones buried deep within archaeological contexts (Martill, 1991). The weight and pressure of the overlying sediment compresses bones into the surrounding sediments, reducing pore spaces. As pore spaces reduce, the underlying sediment becomes denser and provides more resistance to increased overburden pressure. As the pressure from the overburden increases, bones break, warp, or crush (Lyman, 1994).

Bones with higher bone volume density are more resistant to compaction than those with lower bone volume density because they have fewer internal pore spaces (Butler and Chatters, 1994; Nicholson, 1992a; Smith, 2008). Bones with reinforced/robust shapes (contain vertical struts, articular surfaces, and higher cortical to trabecular bone ratio) are also more resistant to compaction (Lyman, 1994). Flat, thin, or elongated bones lack reinforcement/robusticity and are not as resistant to compaction as are other shapes (Nicholson, 1992b). Bones that are unweathered, or green, resist compaction better than weathered bones (Shipman, 1981).

Fish bones are typically less able to withstand compaction pressures than are mammal bones (Lyman, 1994; Nicholson, 1992b; Wheeler and Jones, 1989). Compared to mammal bones, fish bones tend to be smaller, less dense, more fragile, and more easily warped (Witten and Huysseune, 2009). These structural differences causes fish bones to become compacted relatively quickly. Bones (fish) of the jaw, vertebrae, and otoliths tend to be best preserved in archaeological contexts (Nicholson, 1992a, 1992b, 1996a, 1996b, 1998).

Conclusions

Concluding remarks depict the unique nature of the shell midden context and describe the ways that bones (especially fish bones) degrade during syndiagenesis and andiagenesis. Shell middens may contain the remains of shellfish, mammals (including humans), rodents, birds, fish, insects, bacteria, and various other microorganisms; as well as the remains of lichens, fungi, and numerous additional flora (Ambrose, 1967). Shell middens have increased alkalinity,

permeability, and porosity compared to other burial environments (Ceci, 1984; Sanger, 1981). These unique conditions allow for a level of bone preservation not possible under the more acidic conditions typical of most other archaeological contexts (Linse, 1992). Bone preservation is best in near neutral (slightly alkaline- pH=7.88) conditions, and decreases with increasing alkalinity or acidity (Linse, 1992).

The stratigraphy of a shell midden is typically complex with alternating layers, or facies (individual dump episodes), containing greater or lesser amounts of shell and darker and lighter matrix (Stein, 1992a). Stratification may often be lumped into two major contrasting layers: a dark-colored, fine-grained, compact, greasy layer that contains fewer highly fragmented shells on the bottom and a lighter colored, permeable, and porous layer that contains more intact shells on top (Ford, 1992; Stein, 1984; Stein, 1992a). These contrasting layers may indicate that the strata represent two depositional events with two distinct types of material (e.g. distinct cultural events) (see Carlson, 1979; Luebbers, 1978), or the strata represent one depositional event with one type of material and the lower portion has been post depositionally altered (see Ford, 1992; Stein, 1992a).

Most shell midden contexts undergo post-depositional alteration, or weathering (Hole, 1961; Wood and Johnson, 1978). Weathering occurs when water (rainwater or groundwater) is introduced into the shell midden and alters the texture and the composition of the soil matrix (Holliday, 1990; Stein, 1992b). Because shell middens are often porous and permeable, rainwater easily passes (percolates) from the upper layers down through the lower layers. As rainwater moves through the midden the aragonite and calcite components of shell (calcium carbonate) undergo dissolution (ions leach from the shells), which alters the initial chemistries (Ford, 1992; Stein, 1992b; Tucker, 1991).

Because shell middens are often near shorelines and water tables, the lower portions of the midden regularly become saturated by groundwater (e.g. tidewater). Groundwater saturation may cause a shell midden to undergo extreme chemical weathering, causing organic matter and clay to hydrate. Hydration alters the color (darkens) and texture (becomes greasy) of the affected stratum (Stein, 1992b). As hydrated organic matter decomposes, organic acids form and dissolve the calcium carbonate component of the shell midden (Ford, 1992; McCutcheon, 1992; Stein, 1992b). The dissolved calcium carbonate is flushed from the deposit

as the water table flows across the bottom of the shell midden (Ham, 1976; Stein, 1992b; White and Hannus, 1983). In deposits that contain a sufficient amount of organic matter whose decomposition produces organic acids, the entire calcium carbonate portion of the saturated matrix may be dissolved and flushed out of the deposit (Stein, 1992b; White and Hannus, 1983). If sufficient organic acids are lacking, smaller taxa and more fragmented specimens from larger taxa will be the first to dissolve and will be underrepresented in the archaeological record (Ford, 1992). In areas where the groundwater table fluctuates seasonally, a third or middle zone may be present. These groundwater fluctuations cause the middle zone to be more weathered than the upper zone (dry) and less weathered than the lower zone (wet) (Stein, 1992b).

Diagenesis in shell middens begins with the removal of soft tissues by aerobic soil microbes (bacteria, fungi) (Child, 1995a). Microbial action produces organic and carbonic acids, which are buffered by the alkaline component of the shells (from the burial environment) (Linse, 1992). Because bone mineral does not degrade via chemical dissolution, the mineral phase is degraded by fungi and bacteria via microscopic focal destruction (MFD) (Child, 1995b; Hackett, 1981; Marchiafava *et al.*, 1974). Once the bones' mineral phase is breached, the organic phase becomes vulnerable to diagenesis by proteases (Bada, 1971, 1991).

At the same time that the mineral and organic phases of bones are being affected by microbial action, they are also being affected by humic substances from the soil humus layer found in shell midden contexts (Dubach and Mehta, 1963; Hedges, 2002; van Klinken and Hedges, 1995). Humic substances are dark-colored, acidic, predominately aromatic, chemically complex, poly-electrolyte-like substances (Schnitzer and Khan, 1978) that form as a result of the degradation of plant and animal matter (Dubach and Mehta, 1963; van Klinken and Hedges, 1995). Humic substances may be divided into humic acids (soluble in weak alkali), fulvic acids (soluble in a weak acid) and humins (not soluble in weak alkali or acid) (Dubach and Mehta, 1963; van Klinken and Hedges, 1995). Lignin, a complex polymer that binds to cellulose fibers and hardens the cell wall of trees, is a major component of humic substances (Alexander, 1965). Lignin is strong and degrades slowly in depositional contexts (Dubach and Mehta, 1963). When bones enter a shell midden context that contains humic substances such as lignin, the bone protein content cross-links with lignin to form a lingo-protein complex, which is highly resistant to enzymatic destruction (Alexander, 1965; Waksman and Iyer, 1932). This cross-linking allows

bones to withstand the effects of microbial action, but contaminates them in the process (Alexander, 1965). The humin portion is especially difficult to remove from bone because it is not soluble in acid or weak alkali. Protein-humin bonds require gelatinization, which uses a weak acid and heat, to the break bond (Alexander, 1965; van Klinken and Hedges, 1995).

Bones deposited in shell midden contexts may also be affected by other diagenic agents such as weathering (leaching), root etching, turbational processes, compaction, and wave action attrition. Although microbial action usually precedes action from other agents, those agents do not follow a specific order and often occur concurrently. For instance, leaching always accompanies wave action attrition, although wave action attrition does not always accompany leaching.

When the effects of all of the diagenic agents are combined with time since burial estimates, bones from the lower portions of the shell midden may be expected to be less well preserved than bones from the upper portions (Linse, 1992; Lyman, 1994; Martill, 1991; Wood and Johnson, 1978). While biostratinomic agents, leaching, root etching, turbational processes, and MFD would still affect bones from the upper portions, those bones would not be affected by ground water inundation, wave action attrition, compaction, or crystalturbation. Since groundwater inundation, compaction, and crystalturbation often have profound effects on bone preservation, it is not surprising that bones tend to become highly fragmented under these conditions. Bones from the lower portion of the shell midden also tend to be the oldest and have been exposed to the effects of diagenic agents for longer periods.

Fish bones are affected by biostratinomic and diagenic agents to a greater extent than mammal bones are, largely because of structural and chemical differences (see earlier discussion) (Wheeler and Jones, 1989; Szpak, 2011). These differences cause fish bones to be degraded at a faster rate than mammal bones. Therefore, when analyzing fish bones recovered from shell midden contexts, it is essential to realize that the assemblage is biased. As fish bone assemblages may be more biased than mammal bone assemblages; it may not be advisable to compare animal classes (Lyman, 1994).

Chapter 6. Taphonomic Analysis Using Zooarchaeological Methods

Introduction

Mean completeness % and bone volume density (BVD) measurements are used in conjunction with established zooarchaeological abundance measures (NISP, %NISP, MNE, and %MAU) to estimate biostratinomic and diagenic effects on Mink Island fish bones. The chapter is separated into two sections (BVD and mean completeness %) to explore different, but related, aspects of fish bone preservation potential. The objective is to isolate the role that humans played (biostratinomic agents) from the role that natural processes (diagenic agents) played in structuring the Mink Island fish bone assemblage. In some instances the assemblage has been divided into five temporal/cultural zones [UM I (750-455 cal. BP), UM II (1000-750 cal. BP), UM III (1600-1000 cal. BP), LM I (5400-4100 cal. BP), and LM II (6700-5400 cal. BP)] to assess temporal variability of preservation potential.

BVD is presented first to determine if taxa-specific and skeletal element-specific differences in BVD were responsible for structuring the Mink Island fish bone assemblage. NISP, MNE, and %MAU abundance measures are used to ascertain if skeletal elements with higher BVD values (i.e. dentaries, vertebrae, maxillae, etc.) are better preserved and more numerous than skeletal elements with lower BVD values (i.e. basipterygium, operculum, ceratohyal, etc.). The same abundance measures are used to determine if skeletal elements from taxa with higher BVD values (i.e. Pacific cod) are better preserved and more numerous than skeletal elements from taxa with lower BVD values (i.e. Pacific salmon). If skeletal elements with higher BVD values are more numerous, diagenic processes likely structured the fish bone assemblage. Conversely, if skeletal elements with lower BVD values are more numerous, biostratinomic agents (i.e. processing salmon for storage) likely structured the fish bone assemblage.

Mean completeness % values are used together with established abundance measures (NISP and %NISP) to estimate biostratinomic and diagenic effects on Mink Island fish bones in the second section. NISP and %NISP values of fish vertebrae, fish non-vertebrae, and fish bones that are too fragmentary to identify beyond class are calculated for each temporal/cultural zone. If diagenic agents were primarily responsible for structuring the fish bone assemblage,

the number of fish bones that are too fragmentary to identify beyond class will increase over time. Additionally, the number of identifiable vertebrae and non-vertebrae will decrease over time. Any deviation from this pattern may indicate that diagenic agents (i.e. wave action attrition, pH, etc.) unevenly affected the fish bones, or biostratinomic agents (i.e. cooking/burning) were primarily responsible for structuring the fish bone assemblage.

Mean completeness % values of skeletal elements that have been aggregated by temporal/cultural zone are also presented. The objective is to determine if mean completeness % values differ significantly over time. If diagenic agents were primarily responsible for structuring the Mink Island fish bone assemblage, the mean completeness % values will decrease significantly over time. Any deviation from this pattern indicates that diagenic agents unevenly affected the fish bones, or biostratinomic agents were primarily responsible for structuring the fish bone assemblage.

Mean completeness % values of the fish bones that are aggregated by anatomical regions are presented in the following section. The goal is to determine if mean completeness % values differ significantly among anatomical regions. For instance, do the skeletal elements that comprise the branchial arch (pharyngeal plate, epibranchial, ceratobranchial, hypobranchial, basibranchial, urohyal, pharyngobranchial) possess higher preservation potential, as assessed via mean completeness %, than skeletal elements that comprise the mandibular arch (palatine, ectopterygoid, mesopterygoid, quadrate)? Mean completeness % values established in this section are used in the subsequent sections to refine robusticity-based and shape-based assessments of preservation potential.

The role that skeletal element robusticity played in structuring the Mink Island fish bone assemblage is also assessed. Skeletal element robusticity is defined here as the strength or rigidity of a structure relative to body size (e.g. Ruff *et al.*, 1993). Robust fish skeletal elements used for this analysis possess one or more of the following physical features: vertical struts, tooth structures, preopercular posterior wing spines, and jaw/mandibular articular structures. These robust physical features were chosen because they likely augment a skeletal element's ability to withstand the effects of biostratinomic and diagenic agents (especially compressive forces). The objective is to determine if skeletal robusticity, as defined here, is a good indicator of preservation potential. If skeletal element robusticity accurately predicts preservation

potential, robust skeletal elements will possess increased mean completeness % values. Any deviation from this pattern suggests that preservation potential is best assessed using other methods.

The role that skeletal element shape played in structuring the Mink Island assemblage is also evaluated. The skeletal element shape method, as defined here, uses the ratio of maximum width to maximum length (presented as a percentage) as a measure of overall bone shape. Those skeletal elements whose maximum width to length percentages are ≤33.33% are categorized as elongated, those whose maximum width to length percentages range between 33.34%-66.66% are categorized as intermediate, and those whose maximum width to length percentages are ≥66.67% are categorized as compact. The objective is to determine if the two-dimensional (2-D) shape-based categories that are defined here, accurately predict preservation potential in archaeological contexts. If so, compact skeletal elements will possess higher mean completeness % values as compared to intermediate and elongated skeletal elements. Any deviation from this pattern suggests that preservation potential is best assessed using other methods.

Finally, the relationship between mean completeness % values and family-level taxa recovered from Mink Island is examined. The objective is to determine if mean completeness % values differ significantly among the taxa. If one taxon is more fragmentary than another, it is either less able to withstand the effects of diagenic agents or it has been differently affected by biostratinomic agents. If a skeletal element's BVD is known, it is possible to determine if differences in mean completeness % values are primarily the result of diagenic or biostratinomic agents. Those skeletal elements from taxa with higher BVD values (i.e. Pacific cod) should have higher mean completeness % values than those skeletal elements from taxa with lower BVD values (i.e. Pacific halibut and Pacific salmon) if diagenic agents were primarily responsible. Any deviation from this pattern indicates that biostratinomic agents (i.e. cooking/ burning/ butchering/disposal, etc.) played the largest role in structuring the fish bone assemblage.

The data derived from the BVD and the mean completeness % analyses are used to estimate preservation potential of the fish taxa and skeletal elements. The effects of diagenic agents are distinguished from the effects of biostratinomic agents where possible. The

biostratinomic data derived from this chapter are used with established zooarchaeological abundance measures in Chapter 8 to assess human-fish interactions at Mink Island.

Bone Volume Density

Ethnoarchaeological (Binford and Bertram, 1977; Brain, 1967) and experimental data (Haynes, 1980; Marean and Spencer, 1991) are used to suggest that bone preservation and contamination potential is linked to BVD. BVD, in turn, is linked with bone porosity. Skeletal elements that are more porous are less dense than skeletal elements that are less porous. Less dense skeletal elements have greater surface area, and tend to be more easily crushed and broken (Lyman, 1994; Nicholson, 1992a). Broken areas provide diagenic agents access to interior bone surfaces, where degradation and contamination spreads outwards, eventually affecting all of the bone surfaces (Interior and exterior) and phases (mineral and organic) (Marean and Spencer, 1991; Lyman, 1994; Nicholson, 1992a).

Inter-taxa and inter-skeletal element differences in BVD affect preservation and contamination potential, and therefore, affect zooarchaeological and stable isotopic analyses. Taxa with denser bones are thought to be better preserved and, therefore, less contaminated than taxa with less dense bones (Butler, 1990; Butler and Chatters, 1994; Nicholson, 1992b; Smith, 2008). Within a single taxon, more dense skeletal elements are thought to be better preserved and less contaminated than less dense skeletal elements (Smith, 2008). Without mitigating for the effects of BVD mediated attrition, zooarchaeological measures may be skewed in favor of more dense skeletal elements (Butler and Chatters, 1994; Lyman, 1994; Nicholson, 1992a; Smith, 2008). Moreover, stable isotopic values may reflect differences in preservation and contamination rather than differences in ecosystem structure and function (Bocherens *et al.*, 2005).

The role that inter-skeletal element differences in BVD played in structuring the Mink Island fish bone assemblage is assessed by comparing skeletal element-specific BVD measurements to NISP, MNE, and %MAU values. These analyses are completed for Pacific cod and Pacific salmon individually to determine if the two taxa were differentially affected by biostratinomic agents (e.g. processing salmon for storage). BVD measurements were collected

by Smith (2008) for twelve Pacific cod skeletal elements, and BVD measurements were collected by Butler and Chatters (1994) for fifteen Pacific salmon skeletal elements. Skeletal elements with known BVD values comprise a small fraction of skeletal elements found within a complete fish skeleton. Therefore, the taxa and skeletal elements used here serve as proxies for the entire Mink Island fish bone assemblage.

Research Question 1: Did inter-taxa and inter-skeletal element differences in bone volume density (BVD) structure the Mink Island fish bone assemblage? Is there a significant correlation between BVD and abundance (%MAU) among Pacific cod and Pacific salmon skeletal elements from temporal/cultural zones UM I, UM II, UM III, LM I, and LM II?

Null Hypothesis 1a: There is not a significant correlation between BVD and abundance (%MAU) among Pacific cod skeletal elements from temporal/cultural zones UM I, UM II, UM III, LM I, and LM II. H_o: $p \geq .05$

Null Hypothesis 1b: There is not a significant correlation between BVD and abundance (%MAU) among Pacific salmon skeletal elements from temporal/cultural zones UM I, UM II, UM III, LM I, and LM II. H_o: $p \geq .05$

Alternate Hypothesis 1a: There is a significant correlation between BVD and abundance (%MAU) among Pacific cod skeletal elements from temporal/cultural zones UM I, UM II, UM III, LM I, and LM II. H_a: $p < .05$

Alternate Hypothesis 1b: There is a significant correlation between BVD and abundance (%MAU) among Pacific salmon skeletal elements from temporal/cultural zones UM I, UM II, UM III, LM I, and LM II. H_a: $p < .05$

Zooarchaeological Methods 1:

The role that BVD differences played in structuring the Mink Island fish bone assemblage is measured in this section. Pacific cod and Pacific salmon skeletal elements were chosen for analysis because they are abundant within the Mink Island assemblage, and BVD values of select skeletal elements are known (e.g. Butler and Chatter, 1994; Smith, 2008). Those Pacific cod and Pacific salmon skeletal elements with known BVD values were aggregated together into a separate database, which contained the following information: Temporal/ cultural zone, taxon, skeletal element, side, and completeness %. The fish bones from BVD database are used as a proxy for the Mink Island fish bone assemblage to assess density-dependent preservation potential. Pacific cod skeletal elements were analyzed separately from Pacific salmon skeletal elements to determine if BVD differences resulted in different preservation potential. Each taxon was separated into five temporal/cultural zones to determine if temporal variability exists.

NISP values were determined for each taxon and temporal/cultural zone by counting the number of complete and fragmentary skeletal elements (fragmentary vertebrae were not included in NISP counts). MNE values were derived from NISP values using complete or fragmentary skeletal elements with non-repetitive landmarks as the unit of calculation. Skeletal element side, size, and completeness % estimates were used to refine MNE values. MAU values were determined by dividing MNE values by the number of times that a skeletal element occurs within an individual. Average numbers of Pacific cod and Pacific salmon vertebrae were obtained from Mecklenburg *et al.* (2002). Skeletal element abundance (%MAU) was determined for each taxon and zone by dividing MAU values by the highest MAU value in the assemblage.

Statistical Methods 1:

BVD values were compared to %MAU values for each temporal/cultural zone using Spearman's rho and Kendall's tau-b to determine if the densest bones are the most numerous. If the Pacific cod skeletal elements with the highest BVD values (e.g. dentary, maxilla, and vomer) possess the highest %MAU values, the null hypothesis 1a will be rejected. If the Pacific salmon skeletal elements with the highest BVD values (e.g. vertebra, articular, maxilla) possess the highest %MAU values, the null hypothesis 1b will be rejected.

Results: Pacific cod

Pacific cod NISP and MNE values are divided by temporal/cultural zone and are presented in Table 6.1. Pacific cod vertebrae were not differentiated by type (i.e. atlas, thoracic, precaudal, caudal, etc.); therefore, vertebrae BVD measurements were derived from an average of atlas vertebra (0.76 g/cm^3) and first caudal vertebra (0.70 g/cm^3) BVD measurements (Table 6.2). The Pacific cod skeletal elements (Tables 6.1 and 6.2) are presented in ranked order from most dense (e.g. dentary) to least dense (e.g. basipterygium). Associated body region are also presented in Table 6.2 to demonstrate that BVD varies across body regions. As Table 6.1 establishes, the highest NISP and MNE values are associated with vertebrae during all temporal/cultural zones except for LM II. Dentaries possess highest NISP and MNE values than vertebrae within the LM II assemblage. Because the LM II assemblage possesses a small sample size (NISP=41, %NISP=0.83), the values may be skewed by sample size issues. Alternately, the larger number of dentaries as compared to vertebrae may suggest that dentaries are more identifiable than vertebrae when highly fragmented (the LM II is the oldest assemblage recovered from Mink Island).

Table 6.1. Abundance (NISP and MNE) of Pacific cod skeletal elements with known BVD by temporal/cultural zone. Radiocarbon age ranges are calibrated (2-Sigma). Skeletal elements are arranged from most dense to least dense.

Pacific cod	UM I (750-455 BP)		UM II (1000-750 BP)		UM III (1600-1000 BP)		LM I (5400-4100 BP)		LM II (6700-5400 BP)	
Skeletal Element	NISP	MNE	NISP	MNE	NISP	MNE	NISP	MNE	NISP	MNE
Dentary	59	26	121	55	45	14	125	26	11	5
Maxilla	57	13	87	28	22	8	89	26	3	2
Vomer	14	13	37	27	15	12	76	28	5	3
Articular	48	16	90	44	26	11	55	19	9	5
Cleithrum	50	14	43	15	27	9	4	2	0	0
Quadrate	26	11	45	22	17	7	104	28	8	3
Vertebrae	576	576	1243	1243	632	632	1026	1026	3	3
Ceratohyal	12	5	28	10	7	4	4	2	2	2
Opercle	15	7	5	3	5	3	1	1	0	0
Hyomandibular	19	12	26	11	8	4	4	2	0	0
Basipterygium	1	1	4	3	4	3	0	0	0	0
Total	**877**	**694**	**1729**	**1461**	**808**	**707**	**1488**	**1160**	**41**	**23**

Table 6.2. BVD and Rank Order of Pacific cod skeletal elements, after Smith (2008). *average of atlas and first caudal vertebrae.

Body Region	Skeletal Element	BVD Rank	BVD g/cm^3
Cranial	Dentary	1	1.23
Cranial	Maxilla	2	0.92
Cranial	Vomer	3	0.85
Cranial	Articular	4	0.83
Pectoral Girdle	Cleithrum	5	0.79
Cranial	Quadrate	6	0.76
Vertebral Column	Vertebra*	7	0.73
Cranial	Ceratohyal	8	0.66
Cranial	Opercle	9	0.57
Cranial	Hyomandibular	10	0.47
Pelvic Girdle	Basipterygium	11	0.11

%MAU and %MAU rankings are divided by temporal/cultural zone and are presented in Table 6.3. Spearman's rho (r_s) and Kendall's tau-b (t_B) statistical analysis were used to determine that BVD rankings and %MAU values from UM Zones II and I are significantly correlated at $p<.01$; and UM III, LM I, and LM II are significantly correlated at $p<.05$ (see summary statistics at the bottom of Table 6.3). Therefore, BVD played a significant role in structuring the Pacific cod bone assemblage during all temporal/cultural zones at the Mink Island site. The densest bones tend to be the most numerous, therefore, the most accurate abundance estimates will be derived from Pacific cod skeletal elements with the highest BVD values such as the dentary, maxilla, vomer, and articular.

Table 6.3. Pacific cod skeletal elements %MAU and BVD rank values and associated summary statistics. Radiocarbon age ranges are calibrated (2-sigma).

Pacific cod Skeletal Element	BVD Rank	UM I (750-455 BP) %MAU	Rank	UM II (1000-750 BP) %MAU	Rank	UM III (1600-1000 BP) %MAU	Rank	LM I (5400-4100 BP) %MAU	Rank	LM II (6700-5400 BP) %MAU	Rank
Dentary	1	100	1	100	1	96	3	93	3	100	1
Maxilla	2	39	7	76	3	50	6	80	4	38	6
Vomer	3	53	4	60	4	100	1.5	100	1.5	75	3.5
Articular	4	63	2	84	2	63	5	59	6	88	2
Cleithrum	5	57	3	31	7	71	4	5	8	0	N/A
Quadrate	6	39	6	44	6	46	6	100	1.5	50	5.5
Vertebrae	7	45	5	51	5	100	1.5	68	5	75	3.5
Ceratohyal	8	12	10	22	8	25	8	4	9.5	50	5.5
Opercle	9	29	8.5	6	10	21	9	4	9.5	0	N/A
Hyomandibular	10	29	8.5	18	9	29	7	7	7	0	N/A
Basipterygium	11	4	11	4	11	17	10	0	N/A	0	N/A
Summary Statistics		**NISP =887 MAU=24.5 r_s=.817; p=.002 t_B=.648; p=.006**		**NISP =486 MAU=45 r_s =.927; p=.000 t_B=.782; p=.001**		**NISP =176 MAU=12 r_s =.720; p=.013 t_B=.550; p=.019**		**NISP =462 MAU=28 r_s =.731; p=.011 t_B=.547; p=.015**		**NISP =38 MAU=4 r_s =.668; p=.025 t_B=.531; p=.030**	

Results: Pacific salmon

Pacific salmon NISP and MNE values are divided by temporal/cultural zone and are presented in Table 6.4. Skeletal elements are positioned within Table 6.4 from most dense to least dense, to demonstrate how abundance relates to BVD. Pacific salmon vertebrae were not differentiated by type (i.e. atlas, thoracic, precaudal, caudal, etc.) and BVD values were derived from an average of atlas vertebra (0.27 g/cm^3) and first caudal vertebra (0.34 g/cm^3) measurements (Table 6.5). Highest NISP and MNE values were consistently derived from vertebrae (fragmentary vertebrae were not included in NISP counts). The second highest NISP and MNE values were associated with the basipterygia. While high NISP and MNE values derived from vertebrae are expected, high values are not expected from the basipterygium because it has one of the lowest BVD values measured (Table 6.5).

Table 6.4. Pacific salmon abundance (NISP and MNE) of skeletal elements of known BVD by temporal/cultural zone. Radiocarbon age ranges are calibrated (2-sigma).

Pacific salmon Skeletal Element	UM I (750-455 BP)		UM II (1000-750 BP)		UM III (1600-1000 BP)		LM I (5400-4100 BP)		LM II (6700-5400 BP)	
	NISP	MNE	NISP	MNE	NISP	MNE	NISP	MNE	NISP	MNE
Vertebra*	751	751	318	318	142	142	547	547	133	133
Articular	1	1	4	2	0	0	0	0	0	0
Maxilla	5	3	4	2	0	0	0	0	0	0
Dentary	4	2	5	3	0	0	0	0	0	0
Basipterygium	16	9	14	9	9	5	0	0	0	0
Opercle	2	1	0	0	0	0	0	0	0	0
Ceratohyal	0	0	0	0	0	0	0	0	0	0
Total	**779**	**767**	**345**	**334**	**151**	**147**	**547**	**547**	**133**	**133**

Table 6.5. BVD and Rank Order of Pacific salmon after Butler and Chatters (1994: 417, Table 5).* Average of atlas and first caudal vertebra BVD.

Body Region	Skeletal Element	Bone Volume Density (BVD) Rank	BVD g/cm^3
Vertebral Column	Vertebra*	1	0.31
Cranial	Articular	2.5	0.2
Cranial	Maxilla	2.5	0.2
Cranial	Dentary	4	0.19
Pelvic Girdle	Basipterygium	5	0.11
Cranial	Opercle	6	0.07
Cranial	Ceratohyal	7	0.06

Pacific salmon %MAU and %MAU rankings are divided by temporal/cultural zone and are presented in Table 6.6. Spearman's rho (r_s) and Kendall's tau-b (T_B) statistical analyses were used to demonstrate that BVD and %MAU values from all temporal/cultural zones are not significantly correlated (p >.05) (see summary statistics in Table 6.6). In four of the six temporal/cultural zones, vertebrae are ranked number 1; in the remaining two zones, the basipterygium is ranked number 1. Therefore, BVD did not play a significant role in structuring the salmon fish bone assemblage during all temporal/cultural zones at the Mink Island site. The high abundance of vertebrae and basipterygia is indicative of differential cultural processing (e.g. processing for storage), which will be explored further in Chapter 8.

Table 6.6. Pacific salmon ranked BVD and skeletal element representation (%MAU) by temporal/cultural zone. Radiocarbon age ranges are calibrated (2-sigma). Associated summary statistics (Spearman's rho, Kendall's tau-b, and nonparametric correlations).

Pacific Salmon Skeletal Element	BVD Rank	UM I (750-455 BP) %MAU	UM I (750-455 BP) Rank	UM II (1000-750 BP) %MAU	UM II (1000-750 BP) Rank	UM III (1600-1000 BP) %MAU	UM III (1600-1000 BP) Rank	LM I (5400-4100 BP) %MAU	LM I (5400-4100 BP) Rank	LM II (6700-5400 BP) %MAU	LM II (6700-5400 BP) Rank
Vertebra	1	100	1	71	2	44	2	100	1	100	1
Articular	2.5	8	5.5	29	4.5	0	N/A	0	N/A	0	N/A
Maxilla	2.5	21	3	29	4.5	0	N/A	0	N/A	0	N/A
Dentary	4	17	4	36	3	0	N/A	0	N/A	0	N/A
Basipterygium	5	67	2	100	1	100	1	0	N/A	0	N/A
Opercle	6	8	5.5	0	N/A	0	N/A	0	N/A	0	N/A
Ceratohyal	7	0	N/A	0	N/A	0	N/A	0	N/A	0	N/A
Summary Statistics		**NISP =779**		**NISP =345**		**NISP =151**		**NISP =547**		**NISP =133**	
		MAU=12		**MAU=7**		**MAU=4.5**		**MAU=8**		**MAU=2**	
		r_s=.664; P=.104		**r_s=.514; p=.238**		**r_s=.225; p=.628**		**r_s=.618; p=.139**		**r_s=.618; p=.139**	
		T_B=.550; p=.091		**T_B=.359; p=.277**		**T_B=.202; p=.565**		**T_B=.548; p=.130**		**T_B=.548; p=.130**	

Discussion

Among the Pacific cod skeletal elements recovered from each of the temporal/cultural zones, there is a significant correlation ($p<.05$) between BVD and %MAU values. The densest skeletal elements are most numerous, which indicates that diagenic agents (BVD-mediated attrition) played a larger role than biostratinomic agents in structuring the Mink Island Pacific cod bone assemblage. Among the Pacific salmon skeletal elements recovered from each of the temporal/cultural zones, there is not a significant correlation between BVD and %MAU values ($p\geq.05$). Vertebrae and basipterygia tend to be the most numerous skeletal elements. While it is expected to find numerous vertebrae, it is unexpected to find numerous basipterygia because they possess a low BVD value (Table 6.5). Therefore, biostratinomic agents (e.g. processing salmon for storage) played a larger role than diagenic agents (BVD-mediated attrition) in structuring the Pacific salmon bone assemblage.

Completeness/Fragmentation Rates

Differences in fish bone shape, BVD, size, protein content, and lipid content affect preservation potential (Butler and Chatters, 1994; Hanson and Buikstra, 1987; Lyman, 1984, 1994; Nicholson, 1992a, 1996a, 1998; Smith, 2008; Wheeler and Jones, 1989). Skeletal elements that are larger, more robust, have higher BVD, have higher protein content, and have lower lipid content tend to be better preserved than skeletal elements that lack these characteristics (Lyman, 1994; Lyman and O'Brien, 1987; Nicholson, 1996a, 1998). Therefore, it is necessary to complete taphonomic analysis before quantifying an archaeological assemblage using established zooarchaeological methods. Taphonomic analysis is especially important with fish bone assemblages, which tend to be more fragmentary and less well-preserved than are their avian or mammalian counterparts (Butler and Chatters, 1994; Nicholson, 1996a; Smith, 2008).

Skeletal elements that are compact-shaped (thick, round, and width is roughly equal) are thought to have higher preservation potential, as indicated by higher completeness % values, than skeletal elements that are elongated-shaped (thin, flat or arched, and length is twice as long as width) (Nicholson, 1992b). Elongated bones are less able to withstand compressive forces than compact bones. Breakage occurs in the weakest areas of the bone (non-robust areas, arch apex, and thinnest areas), which results in reduced completeness % values (Nicholson, 1996a).

Differences in BVD also affects fish bone preservation and contamination potential. Less dense bones tend to have a larger proportion of uncalcified collagen bundles (lower mineralization) (Moss, 1961, 1963; Neuman and Mulryan, 1968) and less densely packed collagen fibrils (Lee and Glimcher, 1991). When combined, lower mineralization and less densely packed collagen fibrils result in lowered BVD values (Butler and Chatters, 1994; Smith, 2008). Fish bones that have low BVD values are highly susceptible to breakage and degradation within the burial environment (Butler and Chatters, 1994; Nicholson, 1996a; Smith, 2008).

Bone size also mitigates fish bone preservation and recovery rates. Within a single species, bones from larger individuals will have higher BVD values than the same bones from smaller individuals (Smith, 2008). Because increased BVD is linked with higher overall preservation potential, larger skeletal elements from larger taxa tend to be more numerous and

have higher completeness % values than smaller skeletal elements from smaller taxa (Lyman, 1994; Smith, 2008). Small Fish bones also tend to be underrepresented in archaeological assemblages because they regularly pass through commonly used mesh sieve sizes [0.64 cm (1/4 in) or 0.32 cm (1/8 in)] (Casteel, 1972). Although recovery bias does not affect preservation, it is included here because it affects zooarchaeological abundance estimates.

Skeletal element robusticity has also been linked with higher preservation potential within archaeological contexts (Ruff *et al.*, 1993; Lyman, 1994). Robusticity provides strength or rigidity (e.g. vertical struts, tooth structures, preopercular posterior wing spines, and jaw/mandibular articular structures) to the bone structure, which may augment preservation potential. Whether skeletal element robusticity is actually linked with higher preservation potential or higher identifiability potential remains unclear and will be tested.

Protein content differences also affect preservation and contamination potential. Protein comprises much of the organic phase of a bone (Currey, 2002). If the protein content remains intact, bone preservation is good. However, if the protein content begins to degrade, pore spaces increase and diagenic agents (bacterial enzymes) gain access to the bone and degrade it from the inside. Factors such as age, sex, and health affect initial bone protein content, and thus, preservation potential (Lyman, 1994; Nicholson, 1996a). A bone that enters the burial context with higher protein levels will be able to withstand the effects of diagenic processes better than a bone that enters the burial context with lower protein levels (Nicholson, 1996a).

Finally, lipid (triglycerides, cholesterol, and phospholipids) content also affects fish bone survival in burial contexts (Herring, 1972; Wang *et al.*, 2008; Witten and Huysseune, 2009). Higher lipid content of bones deposited in burial environments results in increased putrefaction, which produces increased levels of organic acids as byproducts (Witten and Huysseune, 2009). Organic acid causes the bone collagen component to hydrolyze and swell, causing more rapid degradation in burial environments (Collins *et al.*, 2002). Therefore, bones with higher lipid content tend to be less well preserved in burial environments as compared to bones with lower lipid content.

Despite these differences in skeletal element preservation potential, biostratinomic and diagenic agents affect them in similar ways. Skeletal elements break into smaller pieces of bone

over time. These smaller bones become too fragmentary to identify once they lose their diagnostic landmarks (Lyman and O'Brien, 1987; Lyman, 1994). Ultimately, the small, unidentifiable bones become analytically absent (Lyman and O'Brien, 1987). The frequency of bones that are too fragmentary to identify increases over time as cumulative effects of biostratinomic and diagenic agents degrade the fish bone assemblage (Lyman, 1984). Because some skeletal elements retain their diagnostic landmarks despite being highly fragmented (i.e. dentary, premaxilla, vomer, etc.), the rate at which skeletal elements become too fragmentary to identify is unevenly distributed.

Research Question 2: Are there temporal, inter-taxa, and inter-skeletal element differences in Mink Island fish bone completeness % values? To what extent did the length of time the bones were associated with the burial context, taxonomic groupings, anatomical regions, robusticity categories, and shape categories affect completeness % values?

Null Hypothesis 2a: Completeness % values do not differ significantly among temporal/cultural zones. H_o: $p \geq .05$

Null Hypothesis 2b: Completeness % values do not differ significantly among taxonomic groupings. H_o: $p \geq .05$

Null Hypothesis 2c: Completeness % values do not differ significantly among anatomical regions. H_o: $p \geq .05$

Null Hypothesis 2d: Completeness % values do not differ significantly among robusticity categories. H_o: $p \geq .05$

Null Hypothesis 2e: Completeness % values do not differ significantly among shape categories. H_o: $p \geq .05$

Alternate Hypothesis 2a: Completeness % values differ significantly among temporal/cultural zones. H_a: p<.05

Alternate Hypothesis 2b: Completeness % values differ significantly among taxonomic groupings. H_a: p<.05

Alternate Hypothesis 2c: Completeness % values differ significantly among anatomical regions. H_a: p<.05

Alternate Hypothesis 2d: Completeness % values differ significantly among robusticity categories. H_a: p<.05

Alternate Hypothesis 2e: Completeness % values differ significantly among shape categories. H_a: p<.05

Zooarchaeological and Statistical Methods 2a:

Inter-taxa and inter-skeletal element differences in abundance (NISP, %NISP, MNE, MNI, %MNI, MAU, and %MAU) and mean completeness % values are measured within this section. NISP values are organized by temporal/cultural zone and are compiled for non-vertebrae, vertebrae, and fish bones that are too fragmentary to identify beyond class. %NISP values are compiled by dividing the number of bones from a specific category (i.e. vertebrae) by the total number of bones from a temporal/cultural zone and multiplying the quotient by 100.

Pearson product-moment correlation coefficients are used to assess the relationship between the temporal cultural zones and the %NISP values of vertebrae, non-vertebrae, and too fragmentary to identify beyond class categories. Pearson product-moment correlation coefficient is used to determine if there is a significant difference in mean completeness % values among the temporal/cultural zones at Mink Island.

Zooarchaeological and Statistical Methods 2b:

Inter-taxa (family-level) differences in mean completeness % values are measured using one-way ANOVA statistical analysis. Family-level taxonomic identifications are compared to completeness % values to determine if significant differences are visible across the six taxonomic groups. One-way ANOVA analysis provides mean completeness % values and standard deviation (SD) values. Coefficient of variation (CV) values are calculated by dividing the SD value by the mean completeness % value and multiplying the quotient by 100. The CV values are used to assess the range of variability of completeness % values within each taxon.

Zooarchaeological and Statistical Methods 2c:

Inter-skeletal elemental differences in mean completeness % values are calculated for Mink Island skeletal elements aggregated by anatomical region. The twelve anatomical regions measured for this analysis include olfactory, orbital, occipital, otic, investing bones, lateral skull bones, opercular series, mandibular arch, hyoid arch, branchial arch, pectoral girdle, and pelvic girdle. The vertebral column and caudal skeleton are omitted from this analysis because mean completeness % values were not recorded for these skeletal elements. One-way ANOVA statistical analysis is used to determine if mean completeness % values differ significantly across anatomical regions. Mean completeness % values and SD values were used to calculate CV values, which are used to assess the range of variability within each anatomical region.

Mean completeness % and SD values of Mink Island fish bones aggregated by skeletal element (from all taxa and all temporal/cultural zones) are also calculated using Excel. One-way ANOVA statistical analysis would have produced the same data; however, because 54 different skeletal elements were measured, one-way ANOVA is not appropriate for use with this dataset (Drennan, 2010). Mean completeness %, SD, and CV values are presented for comparison purposes; however, significance is not assessed.

Zooarchaeological and Statistical Methods 2d:

An independent-samples t-test is used to evaluate the relationship between the mean completeness % values of robust and non-robust skeletal elements. SD and CV values are also calculated for both skeletal element groups. Robust skeletal elements contain vertical struts,

tooth structures, preopercular posterior wing spines, or jaw/mandibular articular structures; all other skeletal elements are categorized as non-robust. Because completeness % values were not recorded for vertebrae, they have been omitted from this analysis; however, they would have been included in the robust category.

Zooarchaeological and Statistical Methods 2e:

The role that skeletal element shape (2-D) played in structuring the Mink Island fish bone assemblage is assessed using one-way ANOVA. The statistical test is completed to determine if significant differences in mean completeness % values exist across the three shape categories (e.g. compact, intermediate, and elongated). SD and CV values are also presented to measure variability within each shape category. The shape categories were determined by dividing the maximum width by the maximum length and multiplying the quotient by 100. To overcome sample size limitations, the shape-based analysis was restricted to non-vertebrae skeletal elements belonging to the families Cottidae, Gadidae, Pleuronectidae, and Salmonidae.

Results: Vertebrae, Non-Vertebrae, and Too Fragmentary to Identify beyond Class

The results of the NISP and %NISP values of fish vertebrae, non-vertebrae and fish bones that are too fragmentary to identify beyond class are presented in Table 6.7. The column sample, which was excavated from unit 2S2E, is used here to represent the Upper midden. The column sample was brought back to the laboratory as a bulk sample and screened using 0.32 cm (1/8 in) mesh so that it would be comparable to the fish bones collected from the Lower Midden. The Lower Midden sediments were screened in the field using 0.32 cm mesh (other portions of the Upper Midden were screened using 0.64 cm mesh). Because the column sample assemblage contains substantially fewer bones (N=21,588) as compared to the Lower Midden assemblage (N=78,233) %NISP values are used here to compare assemblages.

Table 6.7. Abundance (NISP, %NISP) of too fragmentary to identify beyond class, non-vertebrae, and vertebrae fish skeletal elements by temporal/cultural zones. Radiocarbon age ranges are calibrated (2-sigma).

Fish bones	UM I (750-455 BP)		UM II (1000-750 BP)		UM III (1600-1000 BP)		LM I (5400-4100 BP		LM II (6700-5400 BP)		LM III (7500-6700 BP)	
	NISP	%NISP	NISP	%NISP	NISP	%NISP	NISP	%NISP	NISP	%NISP	NISP	%NISP
Too fragmentary to identify beyond class	1016	80	7988	82	8575	81	52,266	85	13,959	84	115	86
Non-Vertebrae	121	10	622	6	618	6	2445	4	629	4	4	3
Vertebrae	126	10	1153	12	1369	13	6886	11	1958	12	4	11
Total	**421**	**100**	**9763**	**100**	**10,562**	**100**	**61,597**	**100**	**16,546**	**100**	**123**	**100**

Pearson product-moment correlation coefficients were computed to assess the relationship between the length of time the skeletal elements were buried (temporal/cultural zones) and the %NISP values of fish non-vertebrae, vertebrae, and skeletal elements that were too fragmentary to identify beyond class. There was a strong, positive correlation between %NISP of skeletal elements that were too fragmentary to identify beyond class and the temporal/cultural zones ($r=.904$; $n=6$; $p=.014$). There was a strong, negative correlation between %NISP of non-vertebrae skeletal elements and the temporal/cultural zones ($r=-.916$; $n=6$; $p=.010$). The temporal/cultural zones and %NISP of vertebrae were not significantly correlated ($r=.153$; $n=6$; $p=.772$). Too fragmentary to identify beyond class %NISP values range from 80% (UM I) to 86% (LM II), non-vertebrae %NISP values range from 10% (UM I) to 3% (LM III), and vertebrae %NISP values range from 13% (UM III) to 10% (UM I). A scatterplot summarizes the results (Appendix C.1). These data are consistent with the interpretation that fish skeletal elements became more fragmentary over time. As the length of time that the fish skeletal elements were associated with the burial environment increased, the number of skeletal elements that were too fragmentary to identify beyond class increased and the number of non-vertebrae skeletal elements decreased. These variables are inversely related. The lack of significant correlation among the vertebrae suggests that they are more resistant to destruction than non-vertebrae. The vertical struts in vertebrae augment preservation potential (Rojo, 1987), which allows them to be less susceptible to diagenic agents.

Results: Temporal/Cultural Zones

To determine if the length of time the fish bones were buried at Mink Island, mean completeness % and SD values were calculated for the Upper Midden (UM I-III) and Lower Midden (LM I-II) assemblages using Excel. Mean completeness % and SD values are presented in Table 6.8 and Appendix C.2; CV values are presented in Table 6.8. Pearson's product-moment correlation coefficient analysis revealed that there is a weak, but significant negative correlation between the length of time the bones were buried and mean completeness % values (r=-.170, n=4395, p=.000). These data reveal an overall trend towards lower mean completeness % values over time; however, there is a reversal associated with the LM I assemblage. The LM I (5400-4100 cal. BP) has a lower overall mean completeness % (34.62%) than LM II (6700-5400 cal. BP) (52.38%). If diagenic agents were the primary destructive force, fish bones from LM II should have lower completeness % values than fish bones from LM I because they were buried for a longer period. The lower completeness % value suggests that the LM I assemblage was either more intensely affected by diagenic agents (i.e. wave action attrition, lower pH values, etc.), or that the assemblage was more intensely affected by biostratinomic agents (i.e. cooking/ butchery).

Table 6.8. Mean completeness %, SD, and CV values of Mink Island fish bones aggregated by temporal/cultural zone.

Temporal/Cultural Zone	Mean Completeness %	SD	CV (%)
UM I (750-455 cal. BP)	66.64	32.50	48.77
UM II (1000-750 cal. BP)	53.54	28.73	53.66
UM III (1600-1000 cal. BP)	54.12	29.73	54.93
LM I (5400-4100 cal. BP)	34.62	25.64	74.06
LM II (6700-5400 cal. BP)	52.38	28.02	53.49

Results: Family-Level Taxonomic Groupings

Connections between preservation potential and the fish taxa recovered from Mink Island's Upper Midden (column sample) and the Lower midden assemblages are explored in this section. Previously completed BVD analysis (Butler and Chatters, 1994; Smith, 2008) revealed that Pacific cod, Pacific halibut, and Pacific salmon possess differing preservation potential. Variability in preservation potential, therefore, should result in differing mean completeness % values. If diagenic agents were primarily responsible for structuring the fish bone assemblage, skeletal elements from taxa with higher overall BVD measurements should have higher mean completeness % values. Pacific cod should possess higher mean completeness % values than Pacific halibut and Pacific salmon. If BVD measurements of select skeletal elements from specific species (Pacific cod, Pacific halibut, and king salmon) are used to represent all skeletal elements from entire families, skeletal elements belonging to members of the family Gadidae should possess higher mean completeness % values than those belonging to the families Pleuronectidae and Salmonidae. BVD measurements have not been recorded for the remaining Mink Island taxa (Cottidae, Hexagrammidae, and Scorpaenidae). Although Cottidae and Scorpaenidae skeletal elements appear to be as dense as or denser as Gadidae skeletal elements, their density has not been quantified. Therefore, BVD measurements are of little use in determining taxa-specific preservation potential of the entire range of taxa present within Mink Island fish bone assemblage. To overcome problems associated with incomplete knowledge of BVD values, preservation potential is focused on Gadidae, Pleuronectidae, and Salmonidae skeletal elements. Mean completeness % values of Cottidae, Hexagrammidae, and Scorpaenidae are presented in anticipation that BVD measurements will be available for these families in the near future.

Taxa-specific mean completeness % values were derived from the entire range of non-vertebrae skeletal elements recovered from Mink Island that were identified to skeletal element and taxon. Those skeletal elements that were too fragmentary to identify beyond class have been omitted from the NISP values used here. Taxa-specific skeletal elements that were recovered from all temporal/cultural zones have been combined into one aggregation unit. Because diagenic agents cause fish bones to become more fragmented over time, skeletal

elements from the older contexts tend to be more highly fragmented than skeletal elements from the younger contexts. Associated SD values are high because time is not factored into the equation.

A one-way ANOVA was used to test for significant differences in mean completeness % values among the Mink Island non-vertebrae fish taxa. Mean completeness % values differed significantly across the six taxonomic categories (F=71.50; *df*= 5, 4177; p=.000). However, Tukey post-hoc comparisons of the six taxa revealed that the Hexagrammidae mean completeness % value (M=30.03, 95% CI [39.49, 58.97]) was not significantly different (p>.05) from all other completeness % values. Tukey post-hoc comparisons also revealed that the Salmonidae mean completeness % value (M=64.31, 95% CI, [57.45, 71.16]) was not significantly different from the Pleuronectidae mean completeness % value (M=60.41, 95% CI [58.31, 62.51]). Additionally, Tukey post-hoc comparisons indicated that the Scorpaenidae mean completeness % value (M=45.83, 95% CI [34.36, 57.31]) was not significantly different from the Cottidae (M=43.58, 95% CI [41.89, 45.26]) or Gadidae (M=38.40, 95% CI [37.28, 39.53]) mean completeness % values. Because Hexagrammidae, Scorpaenidae, and Salmonidae possess the lowest NISP values (e.g. 39, 36, and 65, respectively), the lack of significance associated with these taxa may be connected to sample size effects. Additionally, the lack of significance may be because these taxa possess similar BVD measurements, and therefore, possess similar preservation potential. However, because BVD measurements are not available for all taxa, it is not presently possible to evaluate the effects of BVD differences. All other differences in mean completeness percentages among the Mink Island fish taxa are significant at p<.05.

Taxa-specific differences in NISP values, mean completeness % values, SDs, and associated CV values are presented in Table 6.9. Gadidae comprise the largest percentage of the assemblage (53.17%, NISP=2224), followed by Cottidae (27.61%, NISP=1155), Pleuronectidae (15.87%, NISP=664), Salmonidae (1.55%, NISP=65), Hexagrammidae (0.93%, NISP=39), and Scorpaenidae (0.86%, NISP=36) (Appendix C.3). However, because NISP values were derived from skeletal elements that were identifiable to taxon and skeletal element, NISP is not associated with preservation potential. Therefore, interpretations of preservation potential must be derived from the other values within Table 6.9. Mean completeness % values are lowest among Gadidae (38.40%), followed by Cottidae (43.58%), Scorpaenidae (45.83%),

Hexagrammidae (49.23%), Pleuronectidae (60.41%), and Salmonidae (64.31%). These data suggest that Gadidae are more highly fragmented than Pleuronectidae and Salmonidae. SD and CV values associated with the mean completeness % values of all fish taxa are high (Table 6.9). SD values generally increase in association with sample size; however, CV values do not vary in concert with sample size. The low CV values associated with Pleuronectidae and Salmonidae suggests that the skeletal element completeness is consistently higher among these taxa. The high CV values associated with Gadidae and Cottidae suggests that fragmentation differed among these individuals. This pattern is consistent with the interpretation that those Pleuronectidae and Salmonidae skeletal elements that were deposited within the Upper and Lower Midden loci were less intensively processed than Gadidae and Cottidae skeletal elements.

In sum, the one-way ANOVA, Tukey post-hoc comparisons, SD values, and CV values revealed that Gadidae were the most fragmentary, followed by Cottidae, Scorpaenidae, Hexagrammidae, Pleuronectidae, and Salmonidae. The results are consistent with the interpretation that the fish taxa were differentially affected by a combination of biostratinomic and diagenic agents. Because Gadidae possess higher BVD values than Salmonidae and Pleuronectidae (Butler and Chatters 1994; Smith, 2008), Gadidae should possess higher mean completeness % values if diagenic agents were primarily responsible for structuring the assemblage. However, because the opposite pattern is visible, the results indicate that Gadidae were more highly processed than Salmonidae and Pleuronectidae. The increased biostratinomic agent action allowed the Gadidae bones to be more easily degraded by diagenic agents (Nicholson, 1992b). It also appears that Cottidae were more highly processed than other taxa; however, because BVD measurements have not been collected for Cottidae, conclusive determinations cannot presently be made.

Table 6.9. Family- level taxa abundance (NISP), mean completeness %, SD, and CV values of Mink Island fish bones.

Taxa	NISP	Mean Completeness %	SD	CV (%)
Gadidae	2224	38.40	27.03	70.39
Cottidae	1155	43.58	29.13	66.54
Scorpaenidae	36	45.83	33.92	74.01
Hexagrammidae	39	49.23	30.03	61.00
Pleuronectidae	664	60.41	27.58	45.65
Salmonidae	65	64.31	27.67	43.03

Results: Anatomical Regions and Skeletal Elements

One-way ANOVA statistical analysis was used to compare mean completeness % values of skeletal elements aggregated by anatomical region to determine if statistically significant differences exist across 12 anatomical groups. Excel was used to generate mean completeness % and SD values of 54 skeletal elements. Because there are 54 different groups, one-way ANOVA is not the appropriate statistic to use to determine if significant differences in mean completeness % values exist. To overcome problems associated with too many categories, mean completeness %, SD, and CV values are presented in table-form and the discussion is limited to a qualitative description of these data.

NISP, mean completeness %, SD, and CV values of 12 non-vertebrae anatomical regions are presented in Table 6.10. NISP, mean completeness %, SD, and CV values of 54 skeletal elements are presented in Table 6.11. Completeness % values were not recorded for vertebrae; therefore, the vertebral column and caudal skeleton have been omitted from these analyses. The data from the Upper Midden (column sample) and Lower Midden temporal/cultural zones (UM I, UM II, UM III, LM I, and LM II) have been combined, and because fragmentation is connected to the burial duration, high SD and CV values are expected.

Table 6.10. NISP, mean completeness %, SD, and CV values of Mink Island fish bones aggregated by anatomical region.

Anatomical Region	NISP	Mean Completeness %	SD	CV (%)
Lateral Skull Bones	1302	31.71	24.84	78.33
Occipital	191	38.17	21.26	55.70
Opercular Series	879	38.23	26.87	70.29
Pelvic Girdle	63	38.73	29.27	75.57
Orbital	72	40.97	18.55	45.28
Olfactory	213	43.94	24.90	56.67
Mandibular Arch	451	47.25	27.27	57.71
Hyoid Arch	365	53.84	33.33	61.91
Pectoral Girdle	265	57.81	26.35	45.58
Investing Bones	23	61.74	32.29	52.30
Branchial Arch	464	62.61	28.21	45.06
Otic	107	64.21	29.69	46.24

One-way ANOVA statistical analysis revealed that differences in the mean completeness % values of anatomical regions are statistically significant ($F=67.96$; $df=11, 4383$; $P=.000$). Mean completeness % of the fish bone anatomical regions range from 31.71% (lateral skull bones) to 64.21% (otic region) (Table 6.10 and Appendix C.4). Whereas mean completeness % of individual fish skeletal elements range from 25.42% (dentaries) to 100% (radials, basihyals, symplectics, and ethmoids) (Table 6.11). The higher degree of inter-skeletal element differences in mean completeness % values suggests uneven distribution within anatomical regions. Skeletal element abundance (NISP) values are also unevenly distributed within anatomical regions (Table 6.10). NISP values may range from as many as 816 (branchiostegal rays) to as few as 11 (subopercle) within a single anatomical region (opercular series) (Table 6.11). Uneven distribution causes those skeletal elements with low NISP values to become overestimated and those skeletal elements with high NISP values to become underestimated. Even if %NISP values are used to normalize the fish bones to account for differing numbers of bones present within a single individual, the discrepancy between skeletal elements remains high.

Table 6.11. Mean Completeness %, SD, and CV values of Mink Island Skeletal Elements.

Anatomical Region	Skeletal Element	NISP	Mean Completeness %	SD	CV (%)
Olfactory	Ethmoid	1	100.00	N/A	N/A
	Prefrontal	7	67.14	19.76	29.43
	Vomer	199	41.96	24.07	57.36
Orbital	Parasphenoid	72	40.97	18.55	45.28
Occipital	Supraoccipital	2	55.00	21.21	38.56
	Exoccipital	57	30.70	23.44	76.35
	Basioccipital	132	41.14	19.48	47.35
Otic	Sphenotic	42	56.90	29.84	52.44
	Pterotic	15	52.67	28.90	54.87
	Opisthotic	2	45.00	21.21	47.13
	Prootic	19	77.37	27.86	36.01
	Otolith	29	73.45	26.76	46.43
Investing Bones	Nasal	4	77.50	28.72	37.06
	Frontal	11	46.36	35.29	76.12
	Parietal	8	75.00	20.70	27.60
Lateral Skull Bones	Premaxilla	417	31.13	23.79	76.42
	Maxilla	227	26.12	17.70	67.76
	Lachrymal	9	35.56	10.14	28.52
	Dentary	347	25.42	17.37	68.33
	Articular	223	39.64	30.15	76.06
	Retroarticular	31	93.55	13.05	13.95
	Preopercle	48	31.04	25.62	82.54
Opercular Series	Opercle	35	37.14	25.96	69.90
	Subopercle	11	73.64	30.09	40.86
	Interopercle	17	47.65	23.86	50.07
	Branchiostegal Ray	816	37.60	26.62	70.80
Mandibular Arch	Palatine	88	36.48	21.87	59.95
	Ectopterygoid	45	74.44	26.59	35.72
	Mesopterygoid	8	81.25	18.08	22.25
	Quadrate	310	45.48	25.81	56.75
Hyoid Arch	Hyomandibular	80	38.75	23.30	60.13
	Symplectic	2	100.00	0.00	0.00
	Interhyal	76	85.26	18.15	21.29
	Epihyal	101	31.19	26.28	84.26
	Ceratohyal	36	35.28	26.24	74.38
	Hypohyal	62	75.00	24.68	32.91
	Basihyal	8	100.00	0.00	0.00
Branchial Arch	Pharyngeal Plate	93	42.47	26.20	61.69
	Epibranchial	114	61.67	23.83	38.69
	Ceratobranchial	48	45.00	18.10	40.22
	Hypobranchial	49	69.59	25.25	36.28
	Basibranchial	15	98.00	7.75	7.91
	Urohyal	49	63.47	20.67	32.57
	Pharyngobranchial	95	82.32	25.62	31.12
Pectoral Girdle	Posttemporal	84	54.88	17.60	32.07
	Supracleithrum	68	57.21	29.01	50.71
	Scapula	11	52.73	14.89	28.24
	Cleithrum	40	32.50	14.98	46.09
	Postcleithrum	43	78.14	25.00	31.99
	Coracoid	7	61.43	16.76	27.28
	Mesocoracoid	4	87.50	5.00	5.71
	Radials	8	100.00	0.00	0.00
Pelvic Girdle	Basipterygium	16	71.88	27.38	38.09
	Interhaemal Spine	47	27.45	19.94	72.64

In addition to uneven distribution of mean completeness % and NISP values within anatomical regions, there is uneven distribution across anatomical regions. For example, the pelvic girdle is represented by three skeletal elements, whereas the branchial arch is represented by 33 skeletal elements (Rojo, 1991). Uneven distribution overemphasizes the importance of completeness % values from anatomic regions consisting of a few skeletal elements and underemphasizes the importance of completeness % values from anatomical regions comprised of many skeletal elements.

When combined, uneven distribution of mean completeness % and NISP values among individual skeletal elements within the anatomical regions suggest that anatomical regions are inappropriate aggregation units for assessing fish bone preservation potential (fragmentation). Preservation potential is linked to something other than anatomical region variability. In an attempt to explore other possible reasons for uneven distribution, the links between preservation (mean completeness %) and skeletal element robusticity (vertical struts, tooth structures, jaw articular surfaces, and preopercular posterior wing spines), and shape (compact, intermediate, and elongated) are explored in the subsequent sections.

Results: Skeletal Element Robusticity Groupings

Researchers who work with archaeological fish bone assemblages regularly report uneven distribution of NISP values across taxonomic and skeletal element categories (Casteel, 1972; Wheeler and Jones, 1989). Skeletal elements that contain tooth structures (e.g. dentary, premaxilla, vomer, pharyngeal plate, epibranchials, pharyngobranchials, and palatine), jaw articular surfaces (e.g. quadrate, articular, maxilla), vertical struts (e.g. vertebra, basioccipital), and preopercular spines (e.g. preopercle) tend to be more numerous than other fish skeletal elements (Table 6.11). Reasons for this distinction in NISP values has been explored by several researchers using BVD measurements (e.g. Butler and Chatters, 1994; Nicholson, 1996a; Smith, 2008). BVD analysis provides a means to measure the poor spaces within a skeletal element (Butler and Chatters, 1994). Because denser portions of bones are better able to withstand the effects of diagenic agents (especially compressive forces) BVD may be used to assess preservation potential (Nicholson, 1996a). While BVD measurements have been collected for a

few North Pacific Ocean fish species (i.e. Pacific salmon, Pacific cod, and Pacific halibut), BVD measurements have not been collected for most of the fish species recovered from regional archaeological contexts. Of those species that have been measured, BVD values are not available for every skeletal element. Additionally, because multiple BVD measurements that span the length of the skeletal element are needed to assess overall preservation potential, the BVD method is of limited value. Especially with assemblages comprised of taxa and skeletal elements whose BVD values are unknown.

To overcome some of limitations associated with uneven coverage of BVD values, I developed a method that uses the presence or absence of skeletal element robusticity as a means to assess preservation potential. Robust skeletal elements are defined here as possessing additional strength or rigidity that likely augment their ability to withstand the effects of biostratinomic and diagenic agents (especially compressive forces) (e.g. Ruff *et al.*, 1993). Skeletal elements that contain vertical struts, tooth structures, preopercular posterior wing spines, and jaw/mandibular articular structures are considered robust for the purpose of this analysis (Table 6.12, Figure 6.1).

Vertebrae and the anterior portion of basioccipitals (K) have vertical struts that increase rigidity, which helps the bone to resist compressive forces (Figure 6.1) (Rojo, 1991; Wheeler and Jones, 1989). Because compressive forces are responsible for a large proportion of diagenic bone destruction (Nicholson, 1992b), possession of vertical struts increase a bone's overall preservation potential. Although vertebrae contain vertical struts, and would normally be included in the robust skeletal elements category, they are not included here because completeness % values were not recorded for all vertebrae.

Tooth-bearing skeletal elements of the branchial arch (Figure 6.1) [pharyngobranchials (F, G, and H), pharyngeal plate (C), and epibranchial #3 (D)], mandibular arch [palatine-family Cottidae (I)], olfactory region [vomer (A)], and the lateral skull bones [premaxilla (B) and dentary (J)] are robust. These skeletal elements possess a layer of increased ossification (thicker and stronger cortical bone layer) surrounding each tooth, which helps anchor the teeth securely in place during food capture (Wheeler and Jones, 1989). Because cortical bone has increased BVD as compared to trabecular bone (Nicholson, 1992a) and BVD is linked to increased preservation potential, bones with tooth structures are inferred to have increased preservation potential.

Skeletal elements that articulate with the tooth-bearing skeletal elements of the upper and lower jaw [articular (E) and maxilla (M)] have robust areas (articular regions) (Smith, 2008) that increase their ability to withstand the pressures associated with food capture (Figure 6.1). These articular surfaces possess a higher percentage of cortical bone, and as a result, have higher BVD values (see Smith, 2008: 70, Table 13, for Pacific cod and Pacific halibut jaw articular surface BVD values). The articular surface where the lower jaw (articular) connects with the mandibular arch [quadrate (L)] is also robust (Figure 6.1); (see Smith, 2008: 70, Table 13, for Pacific cod and Pacific halibut quadrate articular surface BVD values). Like the articular surface of the maxilla and articular, the articular surface of the quadrate is robust (has increased BVD) to withstand the pressures associated with food capture (Smith, 2008). Increased BVD values are associated with increased preservation potential, and therefore, articulars, maxillas, and quadrates are inferred to have increased preservation potential.

Lastly, the preopercles (N) belonging to the family Cottidae are robust (Figure 6.1). Cottidae preopercles have spines that provide rigidity and support to the gill covering. Preopercular posterior wing spines extend past the distal margin of the operculum (gill covering) and act as predatory deterrent mechanisms (Reynolds, 1979). Preopercular spines appear to be dense, and are inferred to have high BVD values; however, actual BVD values are unknown.

In addition to containing many robust skeletal elements, an individual fish specimen contains many non-robust skeletal elements. Non-robust skeletal elements lack the characteristics that provide rigidity, strength, and support, and therefore, have decreased preservation potential compared to their robust counterparts. Diagenic agents, especially compaction, break individual skeletal elements into increasingly smaller fragments until they become too fragmentary to identify and, thus, become analytically absent (Lyman and O'Brien, 1987). Skeletal elements of the olfactory region (except the vomer), orbital region, occipital region (except the basioccipital), otic region, Investing bones, opercular series, mandibular arch (except the palatine), hyoid arch, pectoral girdle, and the pelvic girdle comprise the bulk of the non-robust skeletal elements. Non-robust skeletal elements typically comprise a relatively small percentage of the identified fish bone assemblage while at the same time comprise a large percentage of fish bones that are too fragmentary to identify beyond class (Nicholson, 1996b; Wheeler and Jones, 1989). Because the presence/absence of robust structures method

developed here is simple to execute, easy to compute, and does not require the use of expensive equipment; it is more assessable to researchers working with mixed fish bone assemblages recovered from the North Pacific region.

Pearson product-moment correlation coefficient was used to assess the relationship between skeletal element robusticity and NISP values. There is a moderately weak negative correlation between the two variables (r=-.438; n=54; p=.001). The lower r value (r=-.438) is because of two factors: Abundance was assessed using NISP values, which does not account the large number of branchiostegal rays found within an individual fish specimen, and not all fish taxa contain preopercles that possess spines. Therefore, these data are skewed by inter-taxonomic differences in robusticity. However, because robust skeletal elements comprise 11 out of the most numerous 13 skeletal elements (Table 6.10), robusticity is a good predictor of abundance.

Table 6.12. Anatomical regions and robust skeletal elements.

Anatomical Region	Robust Skeletal Elements	Reason for Inclusion in Robust Category
Olfactory	Vomer	Tooth Structures
Occipital	Basioccipital	Vertical Struts
Lateral Skull Bones	Premaxilla	Tooth Structures
	Maxilla	Jaw Articular Structure
	Dentary	Tooth Structures
	Articular	Jaw Articular Structure
	Preopercle (Cottidae)	Preopercular Spines
Mandibular Arch	Palatine (Cottidae)	Tooth Structures
	Quadrate	Jaw Articular Structure
Branchial Arch	Pharyngeal Plate	Tooth Structures
	Epibranchial (#3)	Tooth Structures
	Pharyngobranchial	Tooth Structures

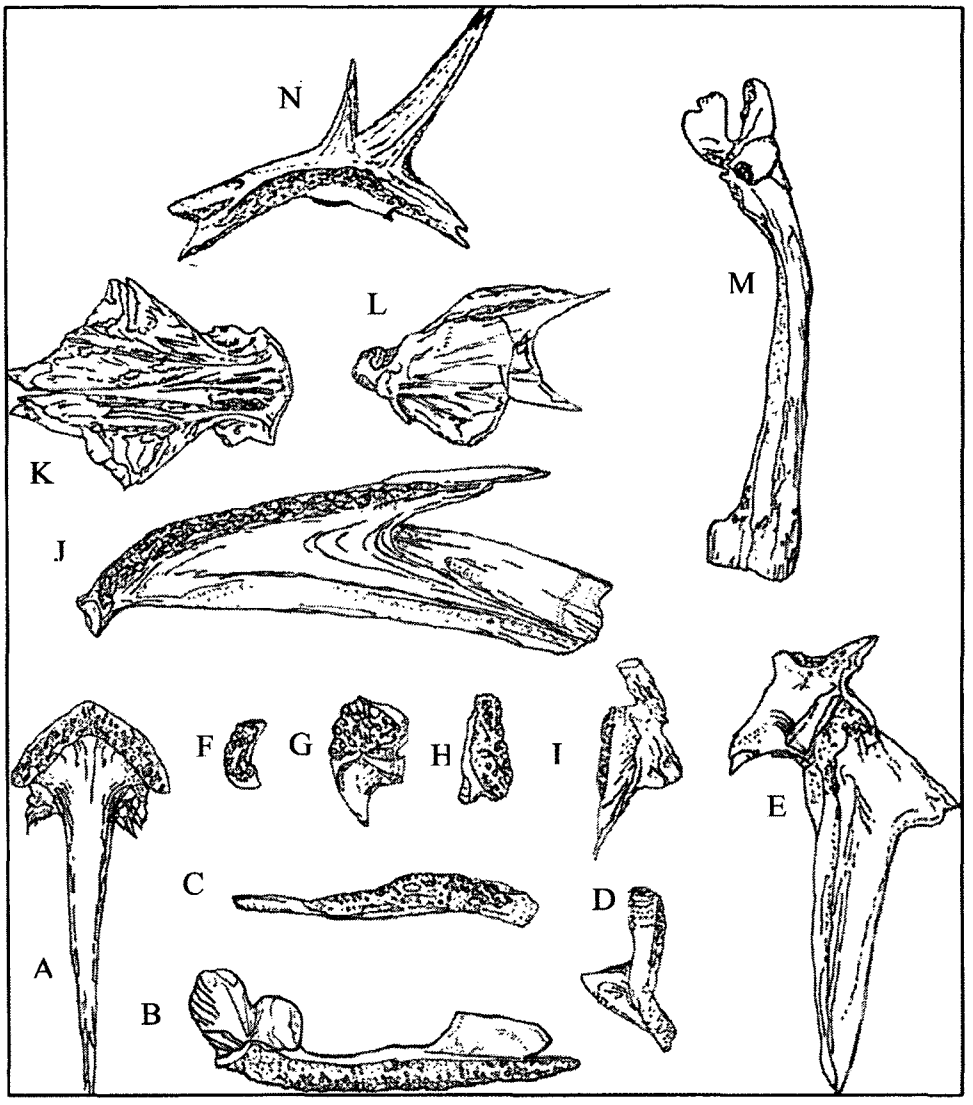


Figure 6.1. Robust skeletal elements. A-H, J-M redrawn from Cannon (1987), N and I are drawn from actual skeletal elements. A= Pacific cod vomer, B= Pacific cod premaxilla, C= Pacific cod pharyngeal plate, D= Pacific cod epibranchial #3, E= Pacific cod articular, F= Pacific cod pharyngobranchial #3, G= Pacific cod pharyngobranchial #2, H= Pacific cod pharyngobranchial #1, I= yellow Irish lord Palatine, J= Pacific cod dentary, K= Pacific cod basioccipital, L= Pacific cod quadrate, M= Pacific cod maxilla, and N= yellow Irish lord preopercle.

An independent-samples t-test was conducted to compare completeness % values of robust and non-robust skeletal elements. If the means are determined to be statistically different, it is possible to say that skeletal element robusticity affected skeletal element completeness % values at Mink Island. The t-test results presented do not assume equal variances because Levene's test for equality of variances revealed that the degree of variability (SD) between robust and non-robust skeletal elements is significantly (2-Tailed) different ($p=.000$, $p<.05$). The mean completeness % for robust skeletal elements (M=37.33, SD=26.32) is significantly lower than the mean completeness % for non-robust skeletal elements (M=49.09, SD=30.10); ($t=-13.80$; $df=8, 4361$; $p=.000$). Non-robust skeletal elements have a higher mean completeness % value than robust skeletal elements, which is opposite of expected if the presence of skeletal element robusticity augmented preservation potential (Appendix C.5).

The SD values associated with the robust and non-robust skeletal elements are high, which demonstrates that another factor besides the presence or absence of robusticity affected preservation potential. CV values provide another means of examining differences in the relationship between mean completeness % and SD values (Eerkens and Bettinger, 2001). High CV values reveal a large degree of variability, whereas low CV values suggest a small degree of variability. CV values are higher among the robust skeletal elements (70.51) compared to non-robust skeletal elements (61.32), which is consistent with the interpretation that another factor besides skeletal element robusticity also affected preservation potential at Mink Island.

Table 6.13. NISP values, mean completeness %, SD, and CV values of non-vertebrae fish bones recovered from the Upper Midden (Column Sample) and Lower Midden loci.

Robust Skeletal Element	Number of Samples	Mean Completeness %	SD	CV (%)
Yes	2144	37.33	26.32	70.51
No	2251	49.09	30.10	61.32

Skeletal element robusticity is connected with higher identifiability potential, as indicated by higher NISP values. Of the total fish bone assemblage NISP value (n=4395), 48.78% (n=2144) was comprised of robust skeletal elements, whereas 51.22% (n=2251) was comprised

of non-robust skeletal elements. Of the total number of different skeletal elements analyzed here (n=55), 21.82% (n=12) were robust, and 78.18% (n=43) were non-robust. If robust and non-robust skeletal elements possessed the same identifiability potential, the mean non-robust skeletal element NISP value should be higher than the mean robust skeletal element NISP value. The mean robust skeletal element NISP value is 184.75 whereas the mean non-robust skeletal element NISP value is 50.00, which is opposite of expected if both groups retained the same identifiability potential. Therefore, highly fragmented robust skeletal elements are more identifiable than are their highly fragmented non-robust skeletal element counterparts.

Robust skeletal elements contain structural features (i.e. tooth structures, vertical struts, jaw articular structures, and preopercular posterior wing spines) that allow the skeletal element to retain its identifiability despite being highly fragmented. Therefore, small fragments of robust skeletal elements are identifiable to taxon (Family-level), skeletal element, and often side. Whereas non-robust skeletal elements lack these highly diagnostic features and become too fragmentary to identify beyond class at a much faster rate. Therefore, skeletal element robusticity is not linked to greater preservation potential, but is linked to greater identifiability

Results: Skeletal Element Shape (2-D)

The role that skeletal element shape has played in structuring archaeofaunal assemblages has been assessed for mammal and avian assemblages (Lyman, 1984; Lyman *et al.*, 1992); however, it is lacking for fish bone assemblages. Reasons for this absence are likely that fish bones are more irregularly shaped than are their mammalian or avian counterparts. Intra- and inter-skeletal element irregularities in overall length, width, and thickness make it difficult to define shape-based categories. BVD measurements represent the best way to measure the role that shape plays in structuring the fish bone assemblage. However, our knowledge of BVD is limited to a few North Pacific fish taxa (Pacific cod, Pacific halibut, and Pacific salmon) and a handful of associated skeletal elements (Pacific Cod= 12, Pacific halibut= 14, and Pacific salmon= 15). Furthermore, currently available BVD measurements do not account for intra-skeletal element variability. In most instances, BVD values have been recorded for the thickest and most robust portion of the skeletal element (Butler and Chatters, 1994; Smith, 2008). While this

approach provides a means to connect abundance (NISP, MNE, and %MAU) with BVD of the portion of the skeletal element that is most likely to survive biostratinomic and diagenic destruction, it is of limited value when attempting to assess fragmentation rates.

In an attempt to overcome some of the limitations associated with incomplete BVD value coverage, a 2-D shape-based analytical method was developed and implemented here. This method uses the ratio of maximum width to maximum length (presented as a percentage) as measure of overall bone shape. The benefit of using the 2-D method is that width to length percentages are simple to collect and record (measurements are derived from modern comparative specimens), and analysis can be completed without expensive equipment. Width and length percentages may be recorded for every skeletal element and every taxon encountered within and archaeological assemblage (assuming you have access to a modern comparative specimen), thereby in increasing our ability to link bone shape with preservation potential.

The shape-based method used here, however, does not account for intra- and inter-skeletal element variability in thickness. Some skeletal elements are thick and rounded (i.e. orbitosphenoid, vertebrae, pharyngobranchial, etc.), while others are flat and thin (i.e. nasals, opercles, interopercles, etc.). Some skeletal elements are thick on one end and are thin on the opposite end (i.e. vomer, articular, dentary, maxilla, premaxilla, etc.). While others may only be defined as irregularly shaped (i.e. opisthotic, prootic, sphenotic, exoccipital, etc.). Intra- skeletal element differences in thickness are not accounted for using the 2-D shape-based method. However, because it is exceedingly difficult to measure intra-skeletal element thickness variability, it has been omitted here. The objective is to determine if the 2-D shape-based method may be used to predict preservation potential (as indicated by mean completeness % value). If significant correlations between width to length percentages and mean completeness % exist, future taphonomic analysis will not be bound by limited BVD data. If significant correlations do not exist, the data suggests that the third dimension (thickness) must be factored in the equation and additional BVD measurements are required.

The 2-D shape-based method was tested and implemented on four family-level taxonomic groups (Gadidae, Cottidae, Salmonidae, and Pleuronectidae). Family-level groups were chosen based on their high abundance (NISP) within the Mink Island archaeological

assemblage. Maximum width to length percentages were collected for 40 different skeletal elements from four species. A Pacific cod specimen was used to represent Gadidae, a yellow Irish lord specimen was used to represent Cottidae, a chum salmon specimen was used to represent Salmonidae, and a Pacific halibut specimen was used to represent Pleuronectidae. Because intra-taxa variability in width to length % values may exist, the shape-based method would be improved if measurements were recorded for additional Pacific cod, yellow Irish lord, chum salmon, and pacific halibut specimens. A lack of duplicate comparative specimens prohibited their inclusion here. Additional width and length percentages covering the range of species present in the Mink Island collection would also augment precision.

Maximum width to length measurements were recorded for 40 skeletal elements from each of the four taxa. Width to length measurements were converted to percentages by dividing the width by the length and multiplying the quotient by 100 (width/length x 100) (Table 6.14). Because the number and composition of skeletal elements vary inter-taxonomically, some width to length percentages are unavailable. In such cases, those percentages have been omitted from the table. Some skeletal elements are represented by a number of variants of the same bone (i.e. ceratobranchial #1 through #4, epibranchial #1 through #4, Pharyngobranchial #1 through #3, etc.). Because these variants are often indistinguishable from one another when highly fragmented (archaeological specimens), width to length measurements have been averaged, and one value represents all variants.

Skeletal elements from the four taxa were aggregated by width to length percentages (Table 6.14). Fish bones with width to length percentages ≤33.33% were aggregated as elongated skeletal elements. Fish bones with width to length percentages between 33.34% and 66.66% were aggregated as intermediate skeletal elements. Fish bones with width to length percentages ≥66.67% were aggregated as compact skeletal elements.

Table 6.14. Maximum width to maximum length %[(W/L) 100] of four taxa. [1]Gadidae is represented by Pacific cod (*Gadus macrocephalus*). [2]Cottidae is represented by yellow Irish lord (*Hemilepidotus jordani*). [3]Salmonidae is represented by chum salmon (*Oncorhynchus keta*). [4]Pleuronectidae is represented by Pacific halibut (*Hippoglossus stenolepis*).

Anatomical Region	Skeletal Element	Gadidae[1] Width to Length %	Cottidae[2] Width to Length %	Salmonidae[3] Width to Length %	Pleuronectidae[4] Width to Length %
Olfactory	Ethmoid	_	43.48	_	100.00
	Prefrontal	69.57	56.00	73.33	48.57
	Vomer	41.27	44.12	23.91	40.00
Orbital	Parasphenoid	21.54	26.88	19.40	17.39
	Alisphenoid	52.00	36.25	100.00	42.86
Occipital	Supraoccipital	31.82	50.57	56.00	42.50
	Exoccipital	80.00	75.23	73.33	82.35
	Basioccipital	73.33	68.18	52.94	58.33
Otic	Sphenotic	53.85	88.59	71.43	75.86
	Pterotic	38.33	65.00	34.48	82.76
	Epiotic	90.00	82.35	50.00	48.28
	Opisthotic	54.90	76.92	64.29	88.89
	Prootic	80.00	95.00	93.75	100.00
	Ototlith	53.33	53.33	50.00	70.00
Investing Bones	Nasal	23.26	33.33	41.67	31.25
	Orbitosphenoid	_	_	91.67	_
	Frontal	65.17	54.01	43.86	48.21
	Parietal	47.62	44.56	50.00	64.71
Lateral Skull Bones	Preopercle	41.25	43.16	33.33	28.57
	Maxilla	17.72	20.86	15.79	22.45
	Lachrymal	41.12	68.18	27.78	_
	Premaxilla	29.51	66.57	62.07	43.90
	Dentary	37.80	35.06	20.45	58.14
	Articular	49.32	56.81	25.35	49.02
	Retroarticular	69.23	55.56	100.00	66.67
Opercular Series	Opercle	61.11	76.30	97.62	100.00
	Subopercle	42.37	80.28	90.63	57.14
	Interopercle	28.30	31.71	43.59	45.28
	Branchiostegal Ray	12.86	10.00	37.93	8.00
Mandibular Arch	Palatine	40.82	35.79	41.67	34.29
	Ectopterygoid	36.07	18.29	40.54	25.00
	Quadrate	60.98	82.76	75.86	69.44
	Metapterygoid	39.47	86.21	87.50	71.43
	Mesopterygoid	27.78	36.84	27.66	28.21
Hyoid Arch	Symplectic	40.91	10.71	31.58	36.36
	Hyomandibular	100.00	71.30	62.16	41.18
	Ceratohyal	33.33	34.57	73.33	47.50
	Interhyal	33.33	20.00	50.00	45.45
	Epihyal	69.70	52.92	70.83	60.00
	Basihyal	_	40.00	_	46.67
	Hypohyal (avg.)	94.45	90.00	92.86	56.57
Branchial Arch	Basibranchial	50.00	33.33	50.00	58.33
	Pharyngeal Plate	12.77	27.40	26.09	16.22
	Ceratobranchial (avg.)	11.69	11.62	18.64	13.21
	Epibranchial (avg.)	30.25	28.81	49.51	36.77
	Pharyngobranchial (avg.)	48.30	65.09	61.85	54.40
	Urohyal	62.86	48.89	25.58	61.29
Pectoral Girdle	Posttemporal	32.73	43.30	35.71	46.15
	Supradeithrum	16.36	62.36	16.67	23.33
	Cleithrum	36.23	24.36	75.41	16.52
	Radial	71.43	42.11	41.67	100.00
	Scapula	75.86	91.19	76.92	81.25
	Postcleithrum	18.89	33.33	28.57	14.29
	Mesocoracoid	_	_	68.18	_
	Coracoid	84.09	66.28	43.59	25.42
Pelvic Girdle	Basipterygium	78.13	38.24	30.00	17.50
	Interhaemal Spine	_	11.67	_	8.70

A one-way ANOVA was used to test for differences in completeness % values among the elongated, intermediate, and compact skeletal elements. Mean completeness % values differed significantly across the three shape categories (F=27.30; *df*=2, 4059; p=.000). Tukey post-hoc comparisons of the three groups reveal that compact skeletal elements (M=51.27, 95% CI [48.82, 53.73]) possessed significantly higher mean completeness % values than Intermediate (M=43.94, 95% CI [42.52, 45.37]), and elongated (M=40.97, 95% CI [39.71, 42.22]) skeletal elements. Tukey post-hoc comparisons demonstrate that the mean completeness % value of Intermediate skeletal elements was significantly higher (p=.006) than the mean completeness % value than elongated skeletal elements.

NISP values, mean completeness %, SD, and CV values are presented in Table 6.15. Although one-way ANOVA reveal that mean completeness % values differed significantly among the three shape-based groups, the large amount of overlap in SD values (Appendix C.6) and high CV values (Table 6.15) suggest that 2-D shape-based categories are not the best method for assessing preservation potential. Skeletal element thickness plays an essential role and must be factored into shape-based calculations. Because BVD values represent the best means of assessing thickness-related preservation potential, additional BVD measurements are required. BVD measurements that cover a wider range of North Pacific fish taxa (especially Cottidae, Hexagrammidae, Scorpaenidae, and Pleuronectidae) and their skeletal elements (multiple measurements across each bone) should be used in conjunction with two-dimensional width and length measurements to produce three-dimensional values.

Table 6.15. Mean completeness %, SD, and CV values of Mink Island fish bones aggregated by 2-D shape categories.

Skeletal Element Shape (W/L*100)	Number of Samples	Mean Completeness %	SD	CV (%)
Elongated (≤33.33%)	1893	40.97	27.81	67.88
Intermediate (33.34-66.66%)	1635	43.94	29.47	67.07
Compact (≥66.67%)	534	51.27	28.87	56.31

Discussion

Results from this chapter demonstrate that the Mink Island fish bone assemblage was structured by a combination of diagenic and biostratinomic agents. Taphonomic analysis of Pacific cod skeletal elements indicates that BVD is significantly correlated with abundance (%MAU) during all temporal/cultural zones. The densest Pacific cod bones tend to be the most numerous, which indicates that diagenic agents played the largest role in structuring the Pacific cod assemblage.

Taphonomic analysis of Pacific salmon skeletal elements shows that BVD is not significantly correlated with abundance (%MAU) during all temporal/cultural zones. The most numerous bones fluctuate between vertebrae (the densest skeletal element) and the basipterygium (one of the least dense skeletal elements) over the temporal/cultural zones. While it is expected to find numerous vertebrae, it is unexpected to find numerous basipterygia. Biostratinomic agents (i.e. differential cultural processing) played a larger role than diagenic agents (i.e. density-mediated attrition) in structuring the Pacific salmon assemblage.

Pearson product-moment correlation coefficients suggest that %NISP values of fish skeletal elements that are too fragmentary to identify beyond class indicate a strong, positive, and significant change over time. This pattern is consistent with what would be expected if diagenic agents played the largest role in structuring the fish bone assemblage. Percent NISP values of fish non-vertebrae indicate a strong, negative, and significant change over time. Again, this pattern demonstrates that diagenic agents played the largest role in structuring the fish bone assemblage. Percent NISP values of vertebrae, however, do not show a significant change over time; %NISP remains relatively stable. While this pattern is different from that seen with bones that are too fragmentary to identify beyond class and non-vertebrae, it shows that diagenic agents played the largest role in structuring the fish bone assemblage. The pattern reveals that fish vertebrae are more resistant to diagenic destruction than other non-vertebrae skeletal elements.

Pearson product-moment correlation coefficient indicates a weak, negative, but significant correlation between mean completeness % values and the Mink Island temporal/cultural zones. While, there is an overall trend towards lower mean completeness %

values over time, there is a reversal associated with the Lower Midden assemblage. Skeletal elements from LM I (5400-4100 cal. BP) have a lower mean completeness % value than skeletal elements from LM II (6700-5400 cal. BP). If diagenic agents were the primary destructive force, skeletal elements from LM II should have a lower mean completeness % value than skeletal elements from LM I because they were associated with the burial environment for a longer period. The lower mean completeness % value demonstrates that the LM II assemblage was either more intensely affected by diagenic agents (i.e. wave action attrition, lower pH values, etc.) or that the assemblage was more intensely affected by biostratinomic agents (i.e. differential processing).

One-way ANOVA statistical analysis was used to demonstrate that the fish taxa recovered from Mink Island possess statistically significant differences in preservation potential, as assessed using mean completeness % values. Biostratinomic agents (differential cooking/burning/butchery/ and disposal) likely played a large role in structuring the fish bone assemblage. Of the taxa with known BVD, Pacific cod skeletal elements are the densest. If diagenic agents (i.e. density mediate attrition) played the largest role in structuring the assemblage, Pacific cod should have the highest preservation potential, as demonstrated by mean completeness % values. The results are opposite of expected, therefore, biostratinomic agents played the larger role in structuring the assemblage. Pacific cod bones were likely more highly processed than the other taxa, which left them more vulnerable to the effects of diagenic agents.

One-way ANOVA statistical analysis was used to demonstrate that mean completeness % values differed significantly among anatomical regions. However, because mean completeness % and NISP values are unevenly distributed within and across anatomical regions, the data are skewed. Within anatomical regions, those skeletal elements with low NISP values become overestimated and those skeletal elements with high NISP values become underestimated. Whereas, across anatomical regions, those regions that are composed of a few skeletal elements become overestimated and those anatomical regions with many skeletal elements become underestimated. When combined, uneven distribution of mean completeness % and NISP values among the individual skeletal elements within and across the anatomical regions suggests that anatomical regions are inappropriate aggregation units for

assessing fish bone preservation potential (e.g. fragmentation). Preservation potential is linked to something other than anatomical region variability.

An independent-samples t-test was used to demonstrate that the mean completeness % value of robust skeletal elements is significantly lower than the mean completeness % value for non-robust skeletal elements. Non-robust skeletal elements have a higher mean completeness % value than robust skeletal elements. This pattern is opposite of expected if the presence of skeletal element robusticity augmented preservation potential. Pearson product-moment correlation coefficient revealed that skeletal element robusticity is significantly correlated (weak negative) with higher identifiability potential, as indicated by higher NISP values. Robust skeletal elements contain structural features (i.e. tooth structures, vertical struts, jaw articular structures, and preopercular posterior wing spines) that allow the skeletal element to retain its identifiability despite being highly fragmented. Therefore, even highly fragmented pieces of robust skeletal elements are identifiable to the family level. Non-robust skeletal elements lack these diagnostic features and become too fragmentary to identify at a much faster rate.

Finally, one-way ANOVA statistical analysis revealed that differences in mean completeness % values differed significantly across the three 2-D shape-based categories (e.g. compact, intermediate, and elongated). Compact skeletal elements possessed significantly higher mean completeness % values than intermediate and elongated skeletal elements. However, the large overlap in SD values and high CV values associated with the shape categories indicate that the 2-D shape-based categories are not the best method for assessing preservation potential. Skeletal element thickness plays an essential role and must be factored into shape-based calculations.

When the different lines of evidence are provided, it is clear that a combination of biostratinomic and diagenic agents structured the Mink Island fish bone assemblage. Differential processing (i.e. cooking and butchering) and differential disposal of the fish taxa and skeletal elements resulted in differential preservation and recovery potential. Those taxa and skeletal elements that were more highly processed were less able to withstand the effects of diagenic agents after they were buried. Once the skeletal elements were buried, they were affected by the same diagenic agent action, which increased over time.

Chapter 7. Taphonomic Analysis Using Stable Isotopic Methods

Introduction

Stable isotopic methods are used in this chapter to measure the effects of biostratinomic (cooking/burning) and diagenic agent (preservation and contamination) action on a sample of 72 ancient (Mink Island) and 31 modern (Gulf of Alaska) Pacific cod skeletal elements. The 72 skeletal elements were recovered from a wide range of radiocarbon-dated (535-5340 cal. BP) levels so that temporal changes, if any, in preservation and contamination may be evaluated. The 31 modern skeletal elements provide baseline preservation and contamination values to which the Mink Island skeletal elements have been compared.

This chapter is divided into two sections (biostratinomic and diagenic agent action), to explore different, but related aspects of fish bone preservation and contamination potential. The goal is to isolate the role that humans (biostratinomic agents) played from the role that natural processes (diagenic agents) played in structuring the Mink Island fish bone assemblage. An additional goal is to separate the effects of leaching (preservation) from the effects of enrichment (contamination) on stable isotope ($\delta^{13}C$, $\delta^{15}N$) values. While the effects of leaching have been widely discussed in stable isotope literature (e.g. Kennedy, 1988; van Klinken and Mook, 1990), the effects of enrichment are largely absent. The research conducted here addresses those gaps in the literature and identifies connections between preservation, contamination, stable isotopic methods, and associated quality control indicators.

The effects of biostratinomic agent action are explored in the first section, which uses stable isotopic methods to determine if color-affecting contaminants (e.g. humic acids, fulvic acids, and humins) can be removed from the 72 Pacific cod skeletal elements so that the cooking/burning stage may be assessed using Petchey and Higham's (2000) method. If the color-affecting contaminants can be removed, the null hypothesis may be rejected, and Petchey and Higham's (2000) method will be used to assess the cooking/burning stage of the Mink Island fish bone samples. If the color-affecting contaminates cannot be removed, the results suggest that other methods (e.g. SEM, X-ray diffraction, etc.) are better suited to assess the cooking/ burning stage of archaeological fish bones.

The ways that diagenic agents affected the Pacific cod skeletal elements (preservation and contamination) is addressed in the second section. Preservation is evaluated by measuring the physical appearance, BB%N, BB%C, and % collagen yield of the 72 pacific cod samples. Contamination is evaluated by measuring the difference in actual versus expected BB%C values (expected BB%C values were determined via linear regression analysis using a formula established by Bocherens *et al.*(2005) for mammals and adapted here for Pacific cod). One-way ANOVA and chi-square statistical analyses are used to determine if significant differences in preservation and contamination values exist among BVD, completeness %, and radiocarbon years BP categories.

The data derived from the preservation and contamination evaluations are used to address the second research question: Is the Pacific cod dentary the best preserved and least contaminated skeletal element, and therefore, the most appropriate skeletal element to use for stable isotope analysis? If the dentary is determined be to possess the lowest preservation/contamination ranking, the null hypothesis may be rejected and the dentary will be selected as most appropriate for stable isotope analysis. If the dentary does not possess the lowest ranking, the alternate hypothesis may be rejected and the skeletal element with the lowest ranking will be selected as most appropriate for stable isotope analysis.

The data derived from the preservation and contamination evaluations are used with the stable isotope values and associated quality control indicators to answer the third research question: Do quality control indicators validate the modified Bell *et al.* (2001) method for archaeological fish bones? The objective is to determine if the modified Bell *et al.* (2001) pretreatment method is gentle enough to use on archaeological fish bones that tend to be small, friable, and poorly preserved. If the stable isotope values of the Mink Island samples meet quality control standards, the null hypothesis may be rejected.

Concluding remarks integrate the cooking/burning stage data with the preservation and contamination data to identify and distinguish between the effects of biostratinomic and diagenic agents on Mink Island Pacific cod skeletal elements. The preservation and contamination data provide insights as to why certain skeletal elements may or may not meet stable isotope quality control standards. Additionally, the data help to identify other factors involved with structuring the Mink Island fish bone assemblage.

Sample Selection Criteria

Modern Samples

A sample of 31 modern Pacific cod dentaries were collected from fish purchased at Taku Smokeries in Juneau, Alaska. The Pacific cod specimens were caught in July 2009 in the Gulf of Alaska. These samples were macerated and were not exposed to heat. Samples were assigned catalog numbers from PC-01 to PC-31.

Although it would have been preferable to analyze quadrate, vomer, hyomandibular, maxilla, and atlas vertebra specimens in addition to dentary specimens to explore inter-skeletal element differences in preservation and contamination potential, cost restraints forced selection of one skeletal element. Dentaries were chosen because they are abundant within the Mink Island assemblage, their BVD values are known (e.g. Smith, 2008), and their total length may be reconstructed from specific bone measurements using linear regression analysis (e.g. Orchard, 2003). Pacific cod were chosen because they are the most abundant taxon in the Mink Island assemblage and they have the highest BVD values of taxa that have been measured (Butler and Chatters, 1994; Smith, 2008).

Archaeological Samples

A sample of 72 Pacific cod dentaries, quadrates, vomers, hyomandibulars, atlas vertebrae, and maxillae were collected from 16 distinct litho-stratigraphic levels (Upper Midden levels 1, 3-7; Lower Midden levels 1-10) from the Mink Island site (Tables 7.1 and 7.2). Samples were assigned catalog numbers HJM-BB-07 to HJM-BB-78 (Appendix D). Pacific cod samples from the Upper Midden were not limited to the column sample because the screen size used to collect the skeletal elements does not affect preservation or contamination potential. Additionally, because the goal is to connect preservation and contamination rates of skeletal elements with the length of time they were associated with the burial environment, I used the most refined radiocarbon dates that were available. For the Upper Midden assemblage, each

stratigraphic level is aggregated separately, whereas for the Lower Midden assemblage, levels 1 through 6 are aggregated together and levels 7 through 10 are aggregated together (Table 7.2).

Pacific cod skeletal elements are not evenly distributed throughout the stratigraphic levels at Mink Island (Table 7.2). Skeletal elements are more abundant in the Upper Midden (<535 to 1510 cal. BP) than the Lower Midden (5047 to 5340 cal. BP). Hyomandibulars are only encountered in the Upper Midden context, but they were selected for analysis because they have low BVD values. The remaining skeletal elements (atlas vertebrae, dentaries, maxillae, quadrates, and vomers), are spread evenly throughout the excavation levels. Upper Midden level 7 and Lower Midden levels 6 through 10 are notable exceptions as there are fewer sampled skeletal elements associated with these contexts. Intact skeletal elements were selected when possible, although few intact samples were present, especially from the Lower Midden contexts.

Table 7.1. Number of Mink Island skeletal elements analyzed from the Upper and Lower Midden assemblages. Radiocarbon age ranges are calibrated (2-sigma).

Skeletal Element	Number of Upper Midden (<535-1510 BP) Samples Analyzed	Number of Lower Midden (5047-5340 BP) Samples Analyzed	Total Number of Samples Analyzed
Dentaries	5	8	13
Quadrates	6	8	14
Vomers	6	8	14
Hyomandibula	6	0	6
Maxillae	5	7	12
Atlas Vertebrae	5	8	13
All Elements	**33**	**39**	**72**

Table 7.2. Mink Island skeletal elements and associated contextual information.

Locus	Stratigraphic level	Calibrated Intercept (Years B.P.)	Temporal /Cultural Zone	Cultural Affiliation	Number of Samples Analyzed
Upper Midden	1	<535	UM I	Thule tradition	6
	3	535	UM I	Thule tradition	6
	4	735	UM I	Thule tradition	3
	4	745	UM I	Thule tradition	3
	5	910	UM II	Thule/Norton/Kachemak tradition	6
	6	915	UM II	Thule/Norton/Kachemak tradition	6
	7	1510	UM III	Norton/Kachemak tradition	3
Lower Midden	1	5047	LM I	Ocean Bay (II) tradition	5
	2	5047	LM I	Ocean Bay (II) tradition	5
	3	5047	LM I	Ocean Bay (II) tradition	5
	4	5047	LM I	Ocean Bay (II) tradition	5
	5	5047	LM I	Ocean Bay (II) tradition	5
	6	5047	LM I	Ocean Bay (II) tradition	1
	7	5340	LM II	Ocean Bay (I) tradition	3
	8	5340	LM II	Ocean Bay (I) tradition	3
	9	5340	LM II	Ocean Bay (I) tradition	3
	10	5340	LM II	Ocean Bay (I) tradition	4

Biostratinomic Agent Action Assessment

Introduction

Heat-induced morphological changes occur when bones are cooked or burned (Richter, 1986; Shipman *et al.*, 1984). These morphological changes affect the bone's preservation potential, leaving them more vulnerable to the effects of other biostratinomic and diagenic agents (Richter, 1986; Shipman *et al.*, 1984). Heating causes physical and chemical alterations within the bone (Brain, 1981; Shipman *et al.*, 1984). These alterations are irreversible and are directly related to the specific temperature to which the bone was heated (McCutcheon, 1992).

Cooking/burning affects organic (collagen) and mineral (hydroxyapatite) portions of the bone at the same time (Johnson, 1989; Shipman *et al.*, 1984). Heating causes collagen fibrils to melt (Szpak, 2011) and hydroxyapatite to melt and recrystallize (Shipman *et al.*, 1984). Heating also causes bones to be more vulnerable to dissolution in acidic burial contexts (Knight, 1985).

When a bone is heated between 300°C and 400°C, "organic char" is produced, which affects biogeochemical values (^{14}C, $\delta^{15}N$, and $\delta^{13}C$) and associated atomic C: N values (Brain and Sillen, 1988:464).

Although a number of methods have been established to assess cooking/burning stage (color assessment, scanning electron microscope, and x-ray diffraction), color assessment is the most commonly used method because it is fast, inexpensive, and easy to use (Brain, 1981; Petchey and Higham, 2000). With color-based methods, thermally induced changes in the bone are measured using Munsell (1954) color plates (Brain, 1981; Kizely, 1973; Petchey and Higham, 2000). Although color-based methods accurately measure the temperature to which modern bones were heated, the same methods are not as accurate for measuring bones recovered from archaeological contexts (Shipman *et al.*, 1984).

Archaeological bones may experience color alterations because of interactions with humic substances, which are not associated with heat exposure. Humic substances are dark-colored and acidic substances (Schnitzer and Khan, 1978) that form because of the degradation of plant and animal matter (Dubach and Mehta, 1963; van Klinken and Hedges, 1995). Humic substances may be divided into humic acids (soluble in weak alkali), fulvic acids (soluble in weak acid), and humins (not soluble in weak alkali or acid) (Dubach and Mehta, 1963; van Klinken and Hedges, 1995). Humic substances must be removed from the bone before the cooking/burning stage may be accurately measured using the Munsell (1954) color-based methods.

Most of the Munsell (1954) color-based methods have focused on mammals and relatively little is known about the effects on fish bones. Petchey and Higham (2000) are a notable exception, as they burned modern barracuda (*Thyrsites atun*) bones and linked the burning stages to Munsell (1954) colors. Although their method worked well for modern fish bones, the absorption of humic substances limits its value for use with archaeological fish bones. Petchey and Higham's (2000) method would be improved if the color affecting contaminants could be removed from archaeological samples using standard stable isotope pretreatment methods (i.e. alkali and acid washes). However, as humin contaminants are not soluble in weak acid or weak alkali (Dubach and Mehta, 1963), they have been traditionally removed via gelatinization, which uses heat combined with a weak acid solution to break bonds (Longin, 1971). Because the objective is to identify cooking/burning stage, heat cannot be used to

remove contaminants. Therefore, the goal here is to determine if humins significantly affect color-based cooking/burning stage assessments.

To determine how humin contaminants affect color, Petchey and Higham's (2000) Munsell (1954) method has been tested on the 72 Mink Island Pacific cod samples. If the Munsell colors obtained from the Mink Island specimens match those published by Petchey and Higham (2000), color may be used to assess cooking/burning stages. However, if the Munsell colors do not match, other methods (i.e. x-ray diffraction and scanning electron microscope) are better suited to assess cooking/burning stages.

Research Question 3: Is it possible to remove color-affecting contaminants (e.g. humic acids, fulvic acids, and humins) from Pacific cod skeletal elements recovered from the Mink Island site so that the cooking/burning stage may be assessed using Petchey and Higham's (2000) method?

Null Hypothesis 3: Color-affecting contaminants cannot be removed from Pacific cod skeletal elements recovered from the Mink Island site, so the cooking/burning stage cannot be assessed using Petchey and Highams' (2000) method. H_o: Munsell (1954) colors do not match Petchey and Higham's (2000).

Alternate Hypothesis 3: Color-affecting contaminants can be removed from Pacific cod skeletal elements recovered from the Mink Island site, so the cooking/burning stage can be assessed using Petchey and Highams' (2000) method. H_a: Munsell (1954) colors match Petchey and Higham's (2000).

Results: Cooking/Burning Stage

Results of the cooking/burning stage evaluation of the 72 Mink Island Pacific cod skeletal elements are presented in the following paragraphs. The methods used for the initial phase of this analysis are as follows: The outer surfaces of individual skeletal elements that were selected for analysis were cleaned with a toothbrush to remove external contaminants.

The skeletal element samples were placed in a test tube with ultrapure water, placed in an ultrasonic clearer for 15 minutes, and rinsed three times. The bones were placed in a freeze-drier overnight, and samples were ground into a fine powder (<63μm) using a ball mill. The untreated powdered bone samples were assigned Munsell (1954) colors. The Munsell (1954) color evaluations were compared to those presented by Petchey and Higham (2000) to identify burning/cooking stages.

Modern barracuda (*Thyrsites atun*) sample descriptions, Munsell (1954) colors, and class (1-5) associations that were prepared by Petchey and Higham (2000) are presented in Table 7.3. Because cream colors are not covered in the Munsell (1954) color plates, the modern fish bones are lacking hue, value, and chroma descriptions. Results of 72 Mink Island Pacific cod specimen color assessments are presented in Appendix E. The results are organized first by skeletal element and then by calibrated radiocarbon years BP. Results include descriptions of the initial Munsell color assessment (on untreated powdered bone), the second color assessment (on NaOH treated powdered bone), and the third color assessment (on NaOH and HCl treated powdered bone).

Table 7.3. Barracuda whole bone samples (after Petchey and Higham, 2000: 142; Steiner *et al.*, 1995: 226). Comparison between Munsell (1954) color and preservation state, Class (1-5).

Sample description	Munsell color of powdered bone	Class
Modern-hard waxy	Cream	1
Not burned- moderately dense	7.5Y 6/4 dull orange	2
Slightly burned- localized and <half carbonized	7.5 YR 5/4 dull brown	3
Lightly burned:>half carbonized	5 YR 3/4 dark reddish brown	3
Fully carbonized (completely black)	2.5 YR 2/2 v. dark reddish brown	2
Localized <half calcined (more black than white)	7.5 YR 4/1 brownish grey	4
>Half calcined (more white than black)	2.5 YR 6/1 reddish grey	4
Fully calcined (completely white)	7.5 Y 7/1 light grey	4/5

Initial Munsell color evaluation results indicate that none of the 72 Mink Island Pacific cod skeletal elements matched the colors presented by Petchey and Higham (2000) (Appendix E and Table 7.3). The Pacific cod specimens trended towards the 10YR page (Appendix E), whereas the barracuda specimens trended towards the 7.5YR page (Table 7.3). While the differences in Munsell values may reflect subtle differences in modern bone color (varying shades of cream), the differences are not great enough to account for the color differences seen here. Therefore, absorption of color affecting contaminants from the burial environment (i.e. humic acids, fulvic acids, and humins) are likely responsible for the differences. To test this assumption, the 72 Pacific cod samples were treated with a ten-minute 0.1 M sodium hydroxide (NaOH) wash to remove alkali-soluble contaminants from the powdered samples. By completing this step, it is possible to measure how humic acid contaminants affected Munsell color assessments.

The Mink Island Pacific cod powdered bones were treated with NaOH, rinsed, and freeze-dried and their Munsell color was re-recorded. The Mink Island specimens revealed little or no change in the Munsell (1954) color after the NaOH wash (Appendix E). The specimens continued to trend towards the 10YR page, however, the values sometimes lowered (became darker) and the chroma sometimes increased (became darker). The results indicate that fulvic acids and humins are darker than are their humic acid counterparts.

To determine how fulvic acid contaminants affected bone color, the powdered Mink Island samples were treated with two 30-minute washes of 0.5M hydrochloric acid (HCl), rinsed, and freeze-dried; their Munsell (1954) color was re-recorded. The Mink Island samples continued to trend towards the 10YR page, however the values sometimes lowered (became darker), and the chroma sometimes increased (became darker) (Appendix E). Therefore, the results indicate that humin contaminants are darker than are their humic acid and fulvic acid contaminant counterparts.

The next step traditionally used to remove the remaining color-affecting contaminants that are not soluble in weak acid or weak alkali (humins) is gelatinization (Longin, 1971). However, because gelatinization uses heat and weak acid to break bonds, it cannot be used for this analysis. Therefore, humin contaminants are still affecting bone color. If a new method, which uses something other than heat to break the bond between the bone protein content and

the humin contaminants, is developed, the Munsell (1954) color-based method will be suitable to assess cooking/burning stage. Until the method is refined, the scanning electron microscope and x-ray diffraction methods (e.g. Shipman, *et al.*, 1984) are better suited to assess cooking/burning stage of fish bones from archaeological contexts.

Although methodological limitations currently prohibit the assessment of the cooking/burning stage of archaeological fish bones, one conclusion may be drawn from experimental research conducted by Richter (1986). Cooking and burning bones causes heat-induced morphological changes that affect a bone's ability to withstand the effects of biostratinomic and diagenic agents (Richter, 1986). Cooking and burning causes collagen fibrils to melt. Melted collagen fibrils are more susceptible to destruction by certain bacteria and their enzymes, which causes rapid degradation (Marchiafava *et al.*, 1974; Richter, 1986). Therefore, if an intact subfossil native collagen fibril is found, that skeletal element was not thermally altered before entering the burial environment (Richter, 1986).

Diagenic Agent Action Assessment

Preservation (Leaching) Assessment

Physical Appearance Class

Following the work of Petchey and Higham (2000), each Mink Island Pacific cod skeletal element was assessed from class 1 ("modern") to class 5 ("extremely poorly preserved") based on interior and exterior physical appearance (McGovern-Wilson, 1992; Petchey and Higham, 2000; Stafford *et al.*, 1988: 2258, Table 1, Stafford *et al.*, 1991: 62-64) (see Table 7. 4 for class descriptions). Skeletal elements were assessed from hard, dense with a waxy luster (class 1) to soft and porous with cracking and flaking (class 5). Any broken and visibly contaminated (i.e. shell dust adhering to the bones) portions of the bone were incorporated into the individual class assessments.

Table 7.4. Classification of bones based on physical properties. After Stafford, Brendel and Duhamel (1988: 2258, Table 1), Stafford *et al.* (1991: 62-64), Petchey and Higham (2000: 138, Table 1).

	Class 1	Class 2	Class 3	Class 4	Class 5
Preservation	Modern (excellent preservation)	Very well to well preserved	Moderately well preserved	Poorly preserved	Extremely poorly preserved
Physical characteristics of whole bone	Waxy luster; dense impermeable mineral matrix	Waxy luster; chalky luster progressively replaces waxy bone from interior toward exterior; loss of concoidal fracturing	Interior and exterior are chalky; surface hardness decreases and porosity increases with decreasing %N; uneven hackly fractures perpendicular to bone's main axis	Similar characteristics to class III, with continued decrease in hardness, increase in porosity.	Soft, easily pulverized bone if inorganic replacement has not occurred. Bones will have low density. If mineralization by carbonates, Fe, Mn or Si occurs, bone will be hard.

Physical appearance class evaluations (ordinal scale) were compared to BVD values using chi-square statistical analysis to determine if evaluations differed significantly among BVD categories. The results of the chi-square analysis indicates that physical appearance class did not differ significantly among BVD categories X^2 (8, N=72) = 12.24, p=.141. The densest bones do not possess the lowest mean physical appearance preservation class values (Figure 7.1, Table 7.4). Associated standard deviation (SD) values are also high, which demonstrates substantial variability in physical appearance class values among the BVD categories. If preservation potential was significantly linked with BVD values, the dentary (BVD= 1.23 g/cm^3) would have lower mean physical appearance class and SD values than the hyomandibular (BVD= 0.47 g/cm^3). The results are opposite from what is expected, and either skeletal element preservation potential is connected to something other than BVD or physical appearance is not a good preservation indicator.

To explore if preservation potential of the Mink Island Pacific cod skeletal elements is linked with cortical bone integrity, physical appearance class values were compared to completeness % values. Chi-square analysis indicates that physical appearance class did not

differ significantly among completeness % categories X^2 (18, N=72) = 20.85, p=.287. The most complete skeletal elements do not appear to be the best-preserved skeletal elements. While the most complete skeletal elements tend to have the lowest mean physical appearance class values, the large amount of overlap associated with the SD values suggests that physical appearance class values are highly variable (Figure 7.2). Therefore, either another factor is affecting preservation potential or physical appearance is not a good preservation indicator.

To determine if the length of time the skeletal elements were buried affected preservation potential, physical appearance class assessments were compared to radiocarbon years BP. The results of chi-square analysis indicates that physical appearance class did not differ significantly among radiocarbon years BP categories X^2 (16, N=72) = 14.89, p=.533. Although skeletal elements from the Lower Midden (5047 - 5340 cal. BP) possess higher mean physical appearance class evaluations values than skeletal elements from the Upper Midden (<535 - 1510 cal. BP), the difference is not significant (Figure 7.3). The results suggest that either another factor is affecting preservation potential or that physical appearance is not a good preservation indicator.

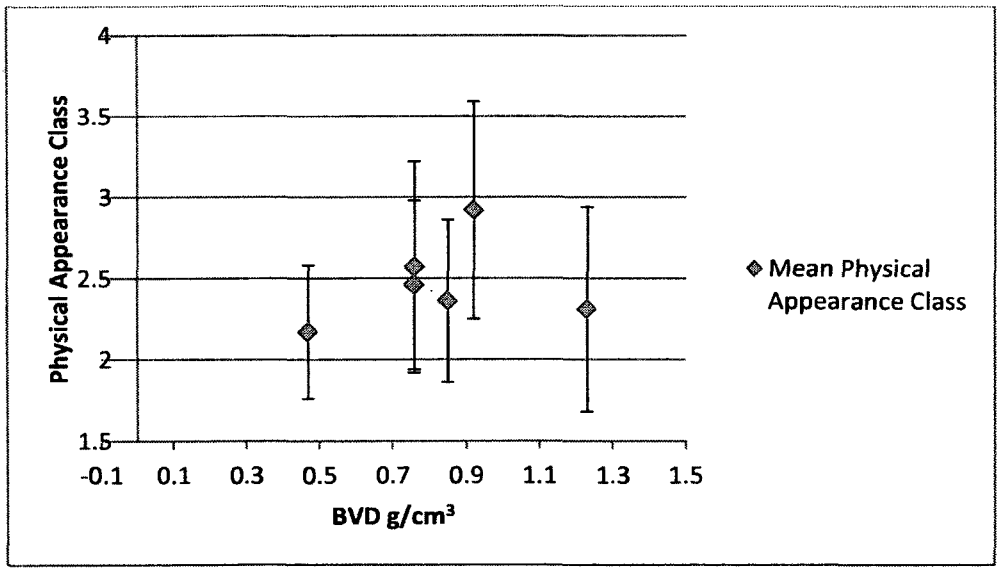


Figure 7.1. Mean physical appearance class and SD values of Mink Island Pacific cod samples aggregated by BVD.

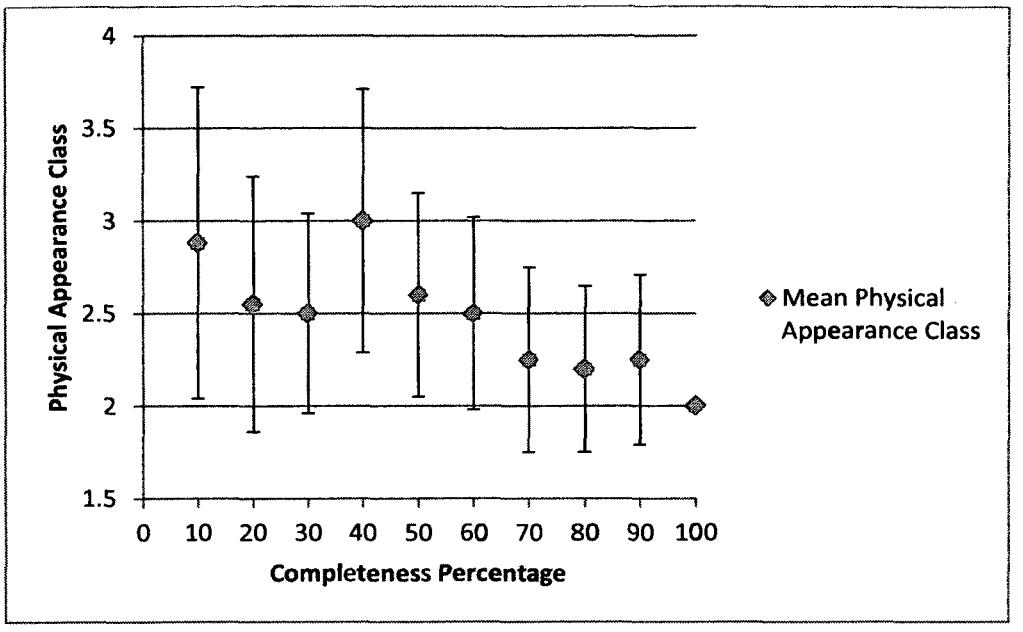


Figure 7.2. Mean physical appearance class and SD values of Mink Island Pacific cod samples aggregated by completeness %.

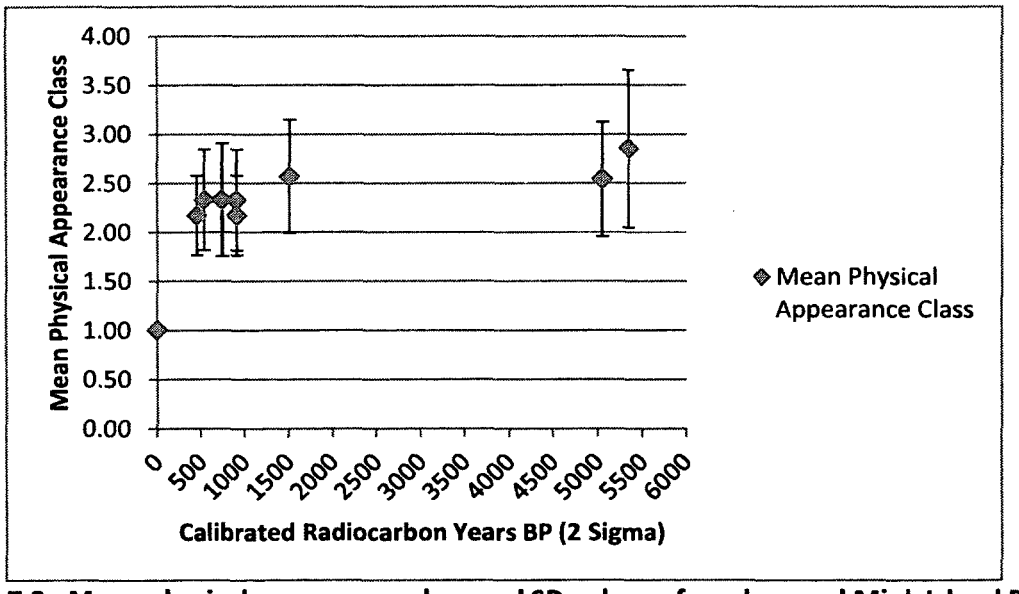


Figure 7.3. Mean physical appearance class and SD values of modern and Mink Island Pacific cod samples aggregated by radiocarbon years BP.

Bulk Bone Percent Nitrogen (BB%N)

BB%N- based preservation assessments were completed on the Mink Island Pacific cod skeletal elements to determine if skeletal elements with higher BVD values are better preserved than skeletal elements with lower BVD values. One-way ANOVA statistical analysis indicates that BB%N values differ significantly (negatively) among the BVD categories (F=2.44; *df*= 5, 66; p=.008) (Figure 7.4). Tukey post-hoc comparisons indicate that the hyomandibular (BVD=0.47) BB%N value (M=3.04, 95% CI [2.80, 3.29]) is significantly higher than the BB%N for all other BVD categories. Therefore, the least dense skeletal element (hyomandibular) has the highest mean BB%N value, which is opposite of expected if increased BVD is linked to increased preservation potential. The results, however, are likely skewed by burial duration. The hyomandibular is represented by six samples recovered from the Upper Midden context (<535 - 1510 cal. BP). No Pacific cod hyomandibulars were recovered from the Lower Midden context (5047 - 5340 cal. BP), and therefore, could not be evaluated. Links between BB%N values and radiocarbon years BP are explored in a later section.

One-way ANOVA statistical analysis was also used to determine if BB%N values differ significantly among completeness % (10-100%) categories. The results indicate that the differences are significant at p<.01 (F=9.13; *df*= 9, 62; p=.000). Tukey post-hoc comparisons indicate that the 10% completeness category (M=1.24, 95% CI [0.81, 1.66]) possessed significantly (p<.05) lower mean BB%N values than all other completeness % categories. Additionally, the 100% completeness category (M=3.12, 95% CI [2.84, 3.40]) possessed significantly (p<.05) higher mean BB%N values than all other completeness categories except the 70% complete (M=2.74, 95% CI [2.09, 3.40]) and the 80% complete (M=2.90, 95% CI [2.54, 3.27]) categories. Therefore, mean BB%N values tend to increase as completeness % values increase, which suggests that the most complete bones tend to be the best-preserved bones (Figure 7.5). However, because there are a few reversals (70% and 80% complete) and the associated standard deviation values are high (Figure 7.5), the data indicate that preservation potential is linked to another factor besides completeness %.

One-way ANOVA statistical analysis was used to test if BB%N values differ significantly among radiocarbon years BP categories to determine if burial duration affected preservation

potential. The results indicate the BB%N values differ significantly ($p<.01$) among the radiocarbon years BP categories ($F=94.00$; $df=9, 93$; $p=.000$). Tukey post-hoc comparisons indicate that as expected, the BB%N values of the modern samples (M=5.00, 95% CI [4.76, 5.24]) were significantly higher than all of the Mink Island samples (Figure 7.6). Additionally, the BB%N values from the Lower Midden contexts 5047 cal. BP (M=1.39, 95% CI [1.69,1.96]) and 5340 cal. BP (M=1.39, 95% CI [1.11,1.68]) were significantly lower ($p<.01$) than all other radiocarbon years BP categories. The test revealed that skeletal elements from more recent stratigraphic levels (Upper Midden) tend to be better preserved (have higher BB%N) than skeletal elements from older stratigraphic levels (Lower Midden) (Figure 7.6). The skeletal elements lost nitrogen content relatively quickly (centennial-scale) after they were deposited within the burial environment as the result of diagenic agents. The rate of nitrogen loss slowed down over time as the skeletal elements reached equilibrium within the burial environment.

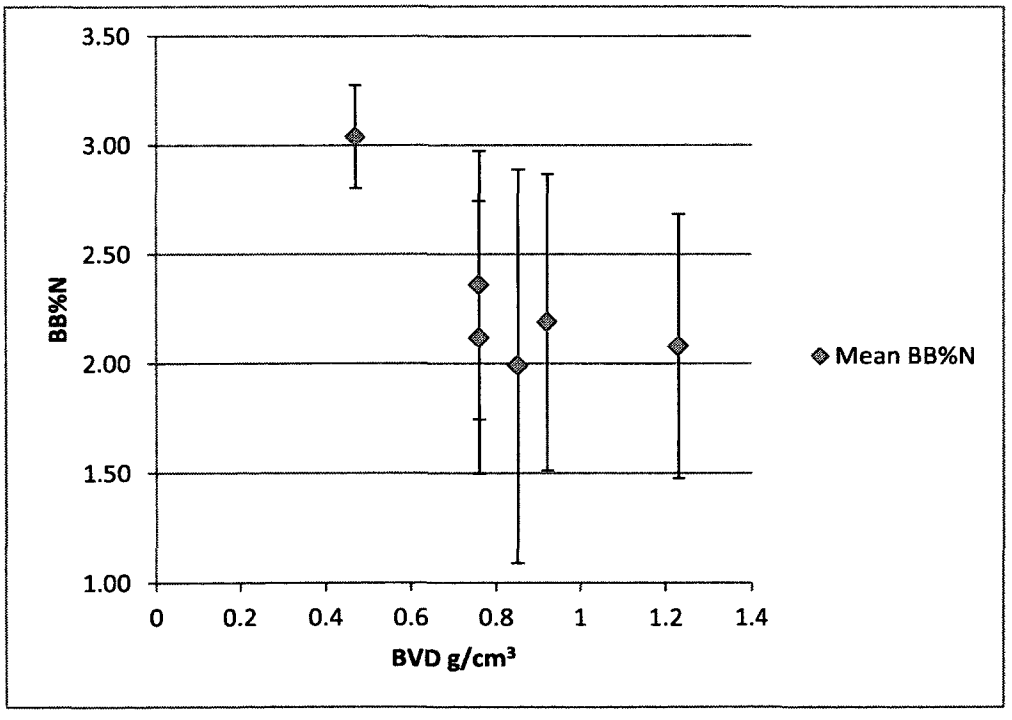


Figure 7.4. Mean BB%N and SD values of Mink Island Pacific cod samples aggregated by BVD.

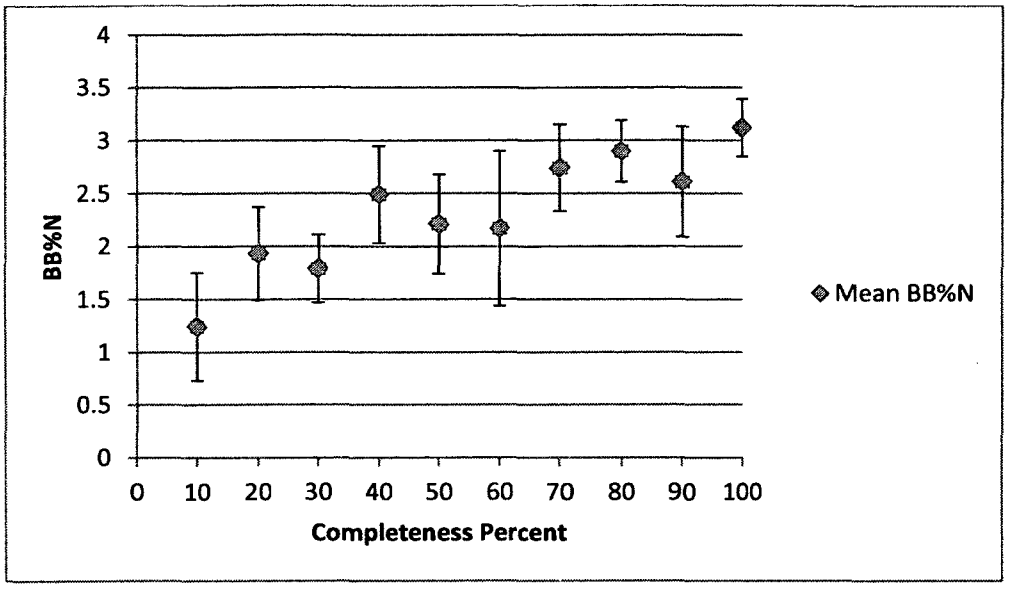


Figure 7.5. Mean BB%N and SD values of Mink Island pacific cod samples aggregated by completeness %.

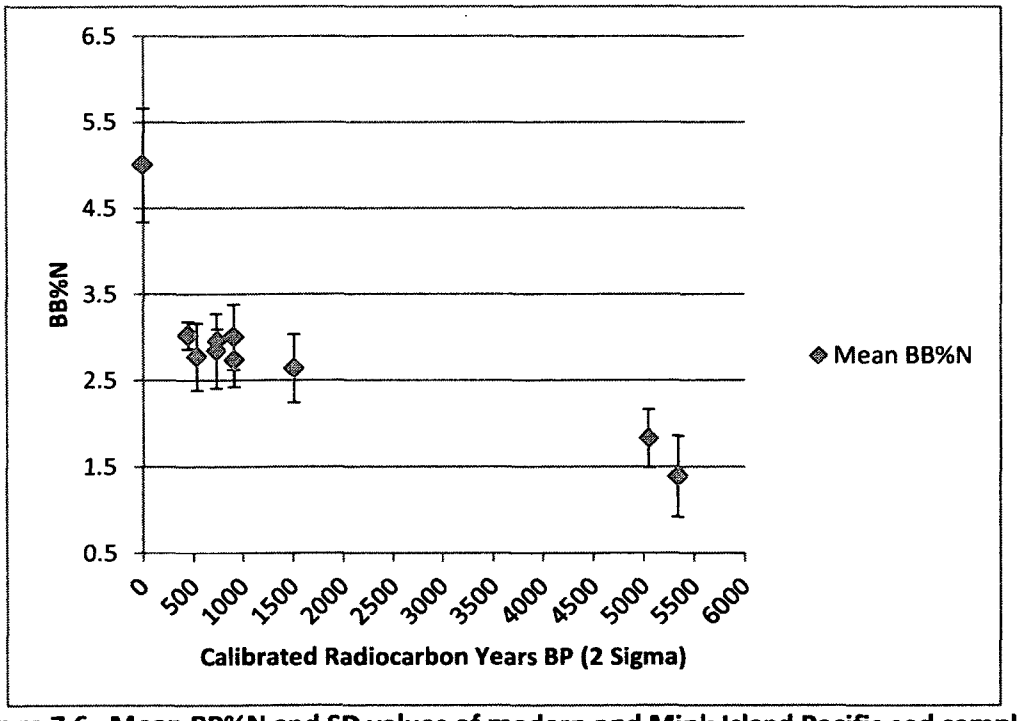


Figure 7.6. Mean BB%N and SD values of modern and Mink Island Pacific cod samples aggregated by radiocarbon years BP.

Bulk Bone Percent Carbon (BB%C)

BB%C- based preservation assessments were completed on the Mink Island Pacific cod skeletal elements to determine if skeletal elements with higher BVD values are better preserved than skeletal elements with lower BVD values. One-way ANOVA statistical analysis revealed that BB%C values do not differ significantly among the six BVD categories (F=2.18; *df*= 5, 66; p=.067) (Figure 7.7). The hyomandibular, which has the lowest BVD value (0.47), has the highest mean BB%C value (M=11.03, 95% CI [10.37,11.69]). If increased BVD augmented overall preservation potential, the hyomandibular should have the lowest mean BB%C value. Hyomandibulars also have the lowest standard deviation values (Figure 7.7). While the hyomandibular's low level of variability of BB%C values is likely linked to burial duration, when the hyomandibular is removed from the analysis, differences in BB%C values among the BVD categories still lack significance (F=1.587; df= 4, 61; p=.189). Therefore, overall preservation potential of the Mink Island Pacific cod skeletal elements is linked with something other than BVD values.

One-way ANOVA statistical analysis was used to determine that BB%C values differ significantly among completeness % (10-100%) categories (F=4.34; *df*=9, 62; p=.000) (Figure 7.8). Mean BB%C values tend to increase as skeletal element completeness % increase, and therefore, the most complete skeletal elements are the best-preserved skeletal elements. The high degree of overlap exhibited in the SD values, however, indicates that BB%C values are highly variable among the completeness % groups. Therefore, another factor is affecting preservation potential at the Mink Island site.

To identify other factors affecting preservation potential, BB%C values were compared to the number of years the skeletal elements were buried. Results of one-way ANOVA statistical analysis are that BB%C values differ significantly among radiocarbon years BP categories (F=30.41; *df*=9, 93; p=.000) (Figure 7.9). Except for two small reversals (910 and 915 cal. BP), the level of BB%C decreases over time. The reversals occurred during the transitional period at the end of the Norton/Kachemak tradition and beginning of the Thule tradition. The increase in BB%C values is likely biostratinomic in nature and may relate to increased levels of contamination by carbon rich sources (e.g. humic substances) rather than increased preservation. Tukey post-hoc comparisons revealed that as with the BB%N values, there is a

significant difference (P<.01) in BB%C values among the modern sample (M=14.09, 95% CI [13.42, 14.76]) compared to the Mink Island samples. Additionally, the Upper Midden samples (<535 - 1510 cal. BP) possesses significantly (p<.01) higher BB%C values than the Lower Midden samples (5047 - 5340 cal. BP). SD values indicate that the greatest amount of variation in BB%C values is seen among the modern and Ocean Bay I samples (Figure 7.9). While it is expected to see high variation among the Ocean Bay I samples (because of contamination), it is unexpected among the modern samples. Either the BB%C content is variable among modern specimens, or the samples were incompletely demineralized during the pretreatment process. This phenomenon will be explored further during the stable isotope quality control indicator section.

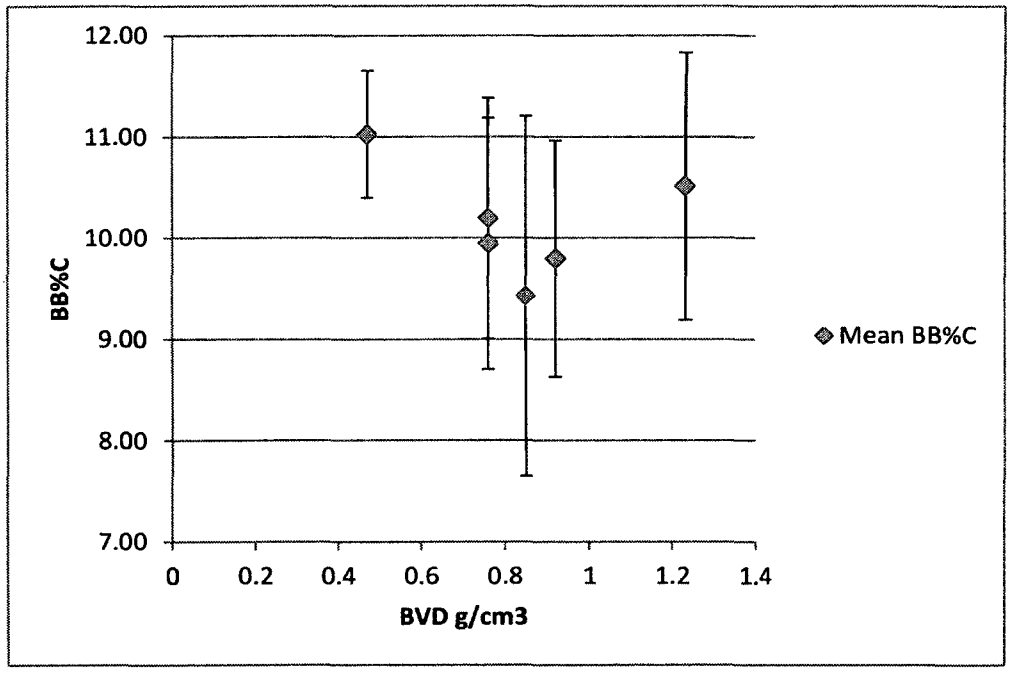


Figure 7.7. Mean BB%C and SD values of Mink Island Pacific cod samples aggregated by BVD.

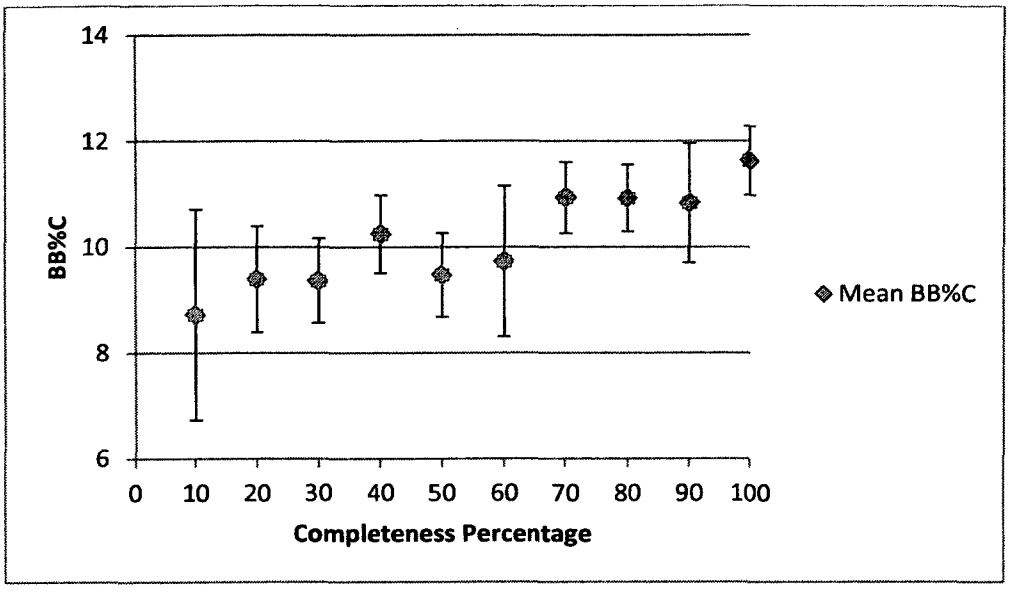


Figure 7.8. Mean BB%C and SD values of Mink Island Pacific cod samples aggregated by completeness %.

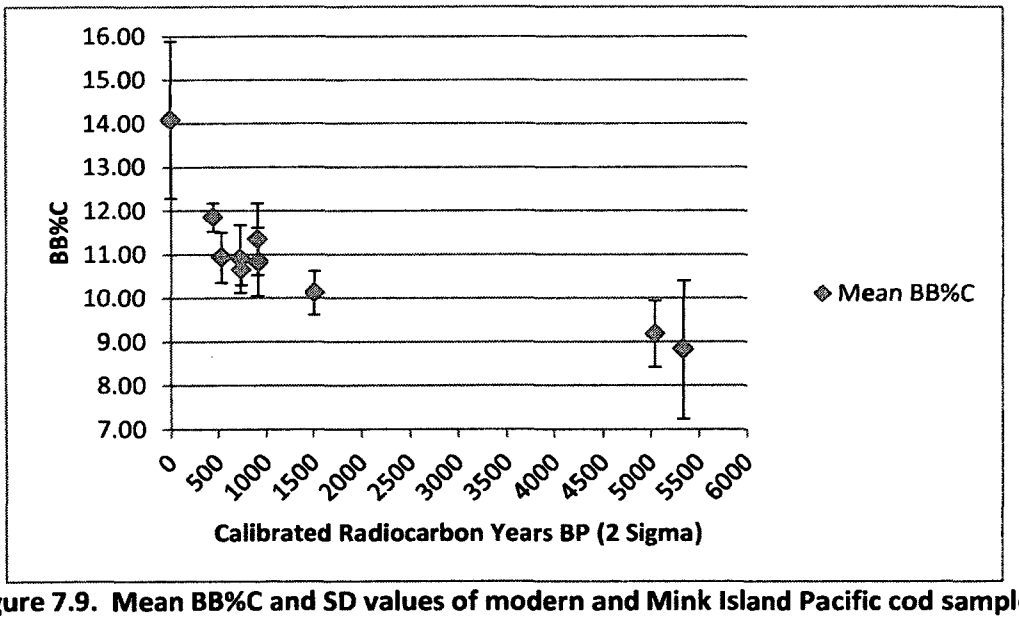


Figure 7.9. Mean BB%C and SD values of modern and Mink Island Pacific cod samples aggregated by radiocarbon years BP.

Percent Collagen Yield

One-way ANOVA statistical analysis was used to determine that the differences in % collagen yield are significantly different (f=3.08; *df*=5, 65; p=.015) among BVD categories (Figure 7.10). The hyomandibular has the lowest BVD value (0.47) and the highest mean % collagen yield (M=15.50, 95% CI [8.65, 22.35]), which is opposite of what would be expected if increased BVD augmented preservation potential (Figure 7.10). While the hyomandibular's high mean collagen yield value is likely linked to burial duration, when the hyomandibular is removed from the analysis, differences in % collagen yield among the BVD categories still lack significance (F= 2.29; *df*= 4,60; p=.070). Therefore, something other than BVD affected skeletal element preservation at the Mink Island site.

To determine if skeletal element preservation is linked to retention of cortical bone integrity, skeletal element % collagen yield values were compared to completeness %. One-way ANOVA statistical analysis confirms that % collagen yield differs significantly among the completeness % (10-100%) categories (F=10.94; *df*=9, 61; p=.000). Mean % collagen yield values decrease as completeness % decrease, therefore, preservation declines as skeletal elements become more fragmentary (Figure 7.11). Associated SD values also decrease as completeness % decrease, however, the most complete specimens have more variable % collagen yield values (Figure 7.11). Another factor besides fragmentation is also affecting preservation potential.

One-way ANOVA statistical analysis was used to determine that % collagen yield differs significantly among radiocarbon year BP categories (F=39.11; *df*= 9, 92; p=.000). Tukey post-hoc comparisons indicate that as expected, the modern skeletal elements have significantly (p<.01) higher % collagen yields (M=23.13, 95% CI [23.38, 23.88) than skeletal elements from the Upper Midden (<535 - 1510 cal. BP) and from the Lower Midden (5047 - 5340 cal. BP) contexts (Figure 7.12). Except for skeletal elements associated with the 735 cal. BP radiocarbon date (M=9.27, 95% CI [6.41, 12.12]), skeletal elements from the Upper Midden context have significantly higher (p<.05) mean % collagen yield values than skeletal elements from the Lower Midden context. Lower % collagen yield values associated with the 735 cal. BP dates (Thule tradition) may be because of increased biostratinomic agent action.

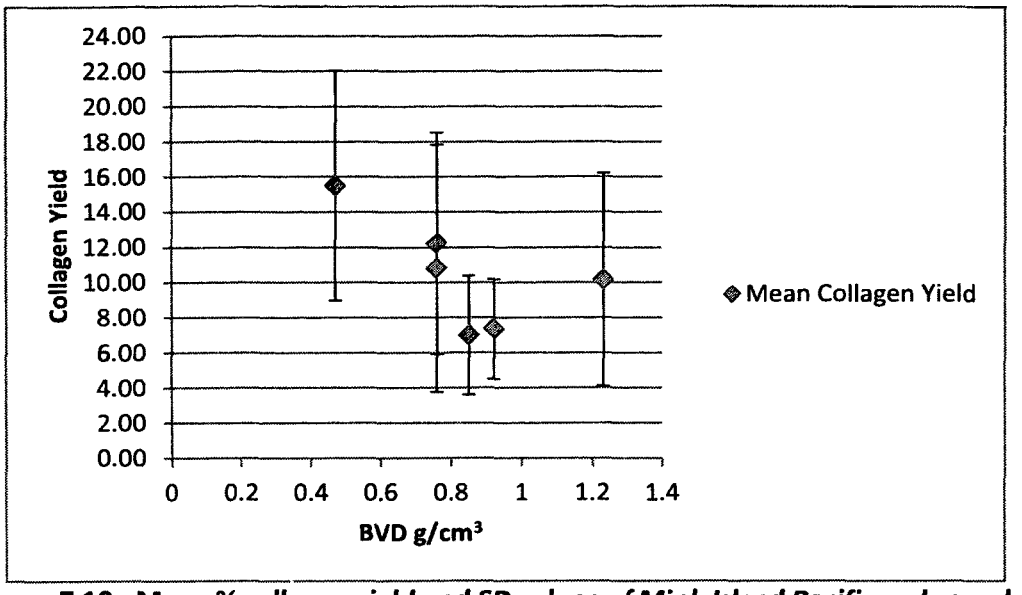


Figure 7.10. Mean % collagen yield and SD values of Mink Island Pacific cod samples aggregated by BVD.

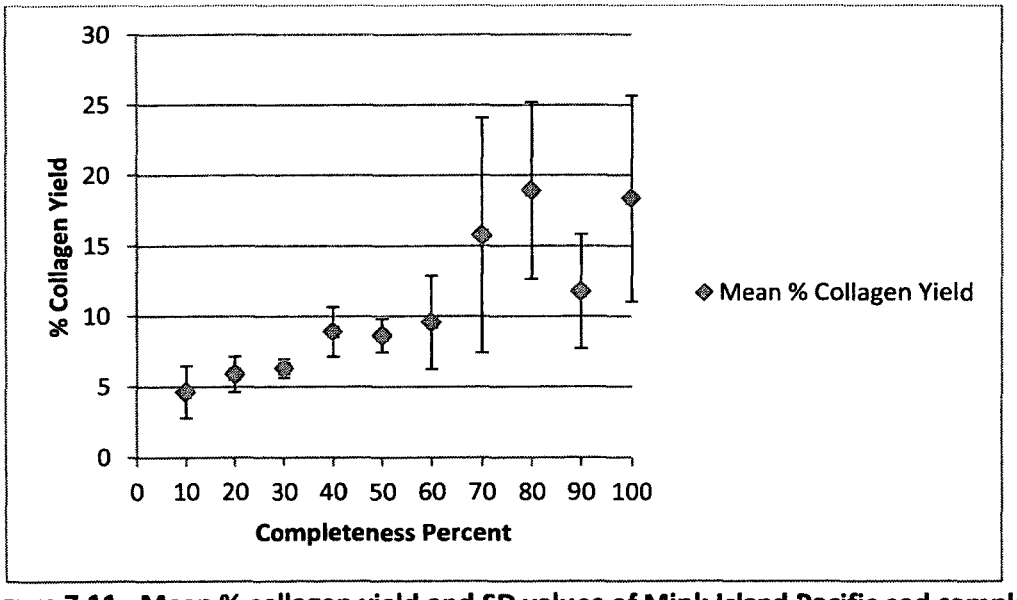


Figure 7.11. Mean % collagen yield and SD values of Mink Island Pacific cod samples aggregated by completeness %.

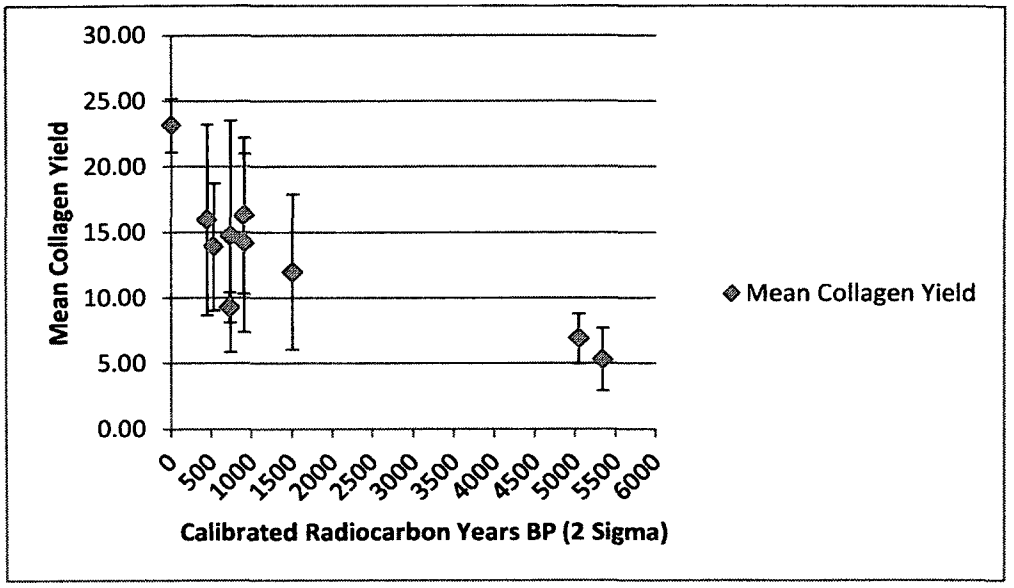


Figure 7.12. Mean % collagen yield and SD values of modern and Mink Island Pacific cod samples aggregated by radiocarbon years BP.

Preservation Conclusions

The results of physical appearance, BB%N, BB%C, and % collagen yield preservation evaluations are combined in this subsection to identify the factor/s affecting the preservation potential of the 72 Mink Island Pacific cod skeletal elements. Results are presented by BVD, completeness %, and radiocarbon years BP so the reliability of the preservation indicators may be evaluated. Preservation values of the 31 modern pacific cod dentaries are presented in Table 7.5 to establish baseline values. Therefore, by subtracting the preservation values derived from the archaeological specimens from the mean preservation values derived from the modern specimens, it is possible to quantify the combined effects of diagenic and biostratinomic agents.

Table 7.5. Preservation indicators (physical appearance class, BB%N, BB%C, and % collagen yield) of modern Pacific cod samples.* indicates rejected value because of low BB%N and BB%C values.

Pacific cod (*Gadus macrocephalus*)				
Sample	**Physical Appearance Class**	**BB%N**	**BB%C**	**% Collagen Yield**
PC-01	1	5.14	14.20	21
PC-02	1	5.09	14.29	22
PC-03	1	5.26	14.61	23
PC-04	1	5.29	14.40	22
PC-05	1	5.31	14.80	22
PC-06	1	4.80	13.59	22
PC-07	1	4.94	13.80	28
PC-08	1	5.07	14.32	23
PC-09	1	5.23	14.88	24
PC-10	1	5.28	14.88	24
PC-11	1	4.99	14.44	22
PC-12	1	4.88	13.91	18
PC-13	1	5.25	14.55	22
PC-14	1	5.17	14.54	23
PC-15	1	5.18	14.72	22
PC-16	1	1.58*	4.76*	22
PC-17	1	5.06	14.48	26
PC-18	1	5.12	14.52	27
PC-19	1	5.09	14.40	19
PC-20	1	5.17	14.63	23
PC-21	1	5.14	14.43	24
PC-22	1	5.27	14.61	22
PC-23	1	5.11	14.39	25
PC-24	1	5.03	14.30	22
PC-25	1	4.51	12.69	24
PC-26	1	5.59	15.75	24
PC-27	1	5.07	14.26	23
PC-28	1	5.14	14.65	23
PC-29	1	5.06	14.21	25
PC-30	1	5.15	14.70	25
PC-31	1	5.03	14.23	25
Mean Values	**1**	**5.11**	**14.41**	**23**

The results of the preservation indicator evaluations (physical appearance, BB%N, BB%C, and % collagen yield) indicate that increased BVD does not augment preservation potential (Table 7.6). While all of the preservation indicators suggested that the hyomandibular was better preserved than the other measured skeletal elements, the results were skewed by the burial duration(hyomandibulars were recovered solely from the Upper Midden). When the hyomandibular values were removed from the preservation indicator tests, preservation still did not differ significantly among BVD categories (Table 7.6).

Table 7.6. Preservation evaluation (physical appearance class, BB%N, BB%C, and % collagen yield) and SD values of Mink Island Pacific cod samples aggregated by BVD. BVD values were obtained from Smith (2008: Table 12, pg. 68).

Preservation Evaluation						
Pacific Cod Skeletal Element	**BVD g/cm^3**	**Number of Samples Analyzed**	**Mean Physical Appearance Class and S.D.**	**Mean BB%N and S.D.**	**Mean BB%C and S.D.**	**Mean Collagen Yield and S.D.**
Dentary	1.23	13	2.31 ± 0.63	2.08 ± 0.60	10.51 ± 1.32	10.16 ± 6.05
Maxilla	0.92	12	2.92 ± 0.67	2.19 ± 0.68	9.80 ± 1.17	7.35 ± 2.83
Vomer	0.85	14	2.36 ± 0.50	1.99 ± 0.90	9.43 ± 1.78	6.99 ± 3.39
Quadrate	0.76	14	2.57 ± 0.65	2.36 ± 0.62	10.20 ± 1.19	10.80 ± 7.04
Atlas Vertebra	0.76	13	2.46 ± 0.52	2.12 ± 0.62	9.95 ± 1.24	12.22 ± 6.3
Hyomandibular	0.47	6	2.17 ± 0.41	3.04 ± 0.24	11.03 ± 0.63	15.50 ± 6.53
All Elements	**N/A**	**72**	**2.49 ± 0.61**	**2.22 ± 0.71**	**9.97 ± 1.38**	**10.01 ± 5.89**

With an exception of physical appearance class evaluations, the indicators (BB%N, BB%C, % collagen yield) suggest that preservation potential differs significantly ($p<.05$) among skeletal element completeness % categories (Table 7.7). As skeletal elements become more fragmentary, preservation drops. Associated SD values among the completeness % categories are highly variable, therefore another factor besides fragmentation is affecting overall preservation potential. The lack of significant differences in mean physical appearance class evaluations among the completeness % categories indicates that skeletal element preservation cannot be accurately measured by physical examination. Skeletal element preservation is, therefore, best assessed using any of the other methods (BB%N, BB%C, and % collagen yield).

Table 7.7. Preservation evaluation (physical appearance, BB%N, BB%C, and % collagen yield) and SD values of Mink Island Pacific cod samples aggregated by completeness %.

Preservation Evaluation					
Completeness Percentage	Number of Samples Analyzed	Mean Physical Appearance Class and S.D.	Mean BB%N and S.D.	Mean BB%C and S.D.	Mean Collagen Yield and S.D.
10	8	2.88 ± 0.84	1.24 ± 0.51	8.72 ± 1.99	4.63 ± 1.84
20	11	2.55 ± 0.69	1.92 ± 0.44	9.39 ± 1.00	5.89 ± 1.28
30	8	2.50 ± 0.56	1.79 ± 0.32	9.36 ± 0.80	6.31 ± 0.68
40	5	3.00 ± 0.71	2.49 ± 0.46	10.24 ± 0.74	8.90 ± 1.76
50	5	2.60 ± 0.55	2.21 ± 0.47	9.47 ± 0.79	8.62 ± 1.19
60	12	2.50 ± 0.52	2.17 ± 0.73	9.73 ± 1.42	9.56 ± 3.30
70	4	2.25 ± 0.50	2.74 ± 0.41	10.93 ± 0.67	15.75 ± 8.35
80	5	2.20 ± 0.45	2.90 ± 0.29	10.93 ± 0.62	18.90 ± 6.27
90	8	2.25 ± 0.46	2.61 ± 0.52	10.83 ± 1.13	11.76 ± 4.06
100	6	2.00 ± 0.00	3.12 ± 0.27	11.63 ± 0.65	18.35 ± 7.31
Total	**72**	**2.49 ± 0.61**	**2.22 ± 0.71**	**9.97 ± 1.38**	**10.01 ± 5.89**

With the exception of physical appearance class evaluations, the indicators (BB%N, BB%C, and percent collagen yield) indicate that preservation potential differs significantly ($p<.05$) among radiocarbon years BP categories (Table 7.8). Modern skeletal elements are significantly better preserved ($p<.05$) than skeletal elements from both Upper and Lower Midden contexts. However, skeletal elements from Upper Midden contexts are not better preserved than skeletal elements from Lower Midden contexts ($p\geq.05$). Based on these data, skeletal elements are leached quickly (centennial-scale) after burial. The rate of leaching decreases as the skeletal elements achieve equilibrium (chemically) with the burial environment. As long as equilibrium is maintained within the shell midden, preservation remains good, however, if conditions change, diagenesis continues until equilibrium is attained again. The decrease in preservation and increase in SD values associated with the Lower Midden Ocean Bay I level (5340 cal. BP) is indicative of increased diagenic agent action associated with being at the base of the shell midden. Skeletal elements from the Ocean Bay I levels were affected by the combined effects of compaction and leaching (rainwater and groundwater) more than skeletal elements from the other contexts. This phenomenon is explored further in the contamination evaluation section.

Table 7.8. Preservation evaluation (physical appearance, BB%N, BB%C, and % collagen yield) and SD values of modern and Mink Island Pacific cod samples aggregated by calibrated radiocarbon years BP.

		Preservation Evaluation				
Calibrated Radiocarbon Years BP (2 Sig.)	Cultural Affiliation	Number of Samples Analyzed	Mean Physical Appearance Class and S.D.	Mean BB%N and S.D.	Mean BB%C and S.D.	Mean Collagen Yield and S.D.
0	Modern	31	1.00 ± 0	5.00 ± 0.66	14.09 ± 1.80	23.13 ± 8.86
<535	Thule	6	2.17 ± 0.41	3.02 ± 0.16	11.85 ± 0.32	15.93 ± 7.27
535	Thule	6	2.33 ± 0.52	2.77 ± 0.39	10.93 ± 0.58	13.88 ± 4.84
735	Thule	3	2.33 ± 0.58	2.84 ± 0.43	10.90 ± 0.77	9.27 ± 1.15
745	Thule	3	2.33 ± 0.58	2.95 ± 0.15	10.65 ± 0.35	14.70 ± 8.84
910	Thule/Norton/Kachemak	6	2.33 ± 0.52	3.00 ± 0.38	11.35 ± 0.82	16.27 ± 5.96
915	Thule/Norton/Kachemak	6	2.17 ± 0.41	2.73 ± 0.31	10.83 ± 0.79	14.20 ± 6.78
1510	Norton/Kachemak	3	2.57 ± 0.58	2.64 ± 0.40	10.12 ± 0.50	11.97 ± 5.92
5047	Ocean Bay II	26	2.54 ± 0.58	1.83 ± 0.34	9.18 ± 0.76	6.88 ± 1.90
5340	Ocean Bay I	13	2.85 ± 0.80	1.39 ± 0.47	8.82 ± 1.58	5.30 ± 2.39
All Periods	**All Traditions**	**103**	**2.49 ± 0.61**	**3.06 ± 1.45**	**11.21 ± 2.43**	**13.99 ± 7.88**

Contamination (Enrichment) Assessment

Introduction: Expected Versus Actual BB%C

BB%C may be used as a preservation indicator because it measures the amount of carbon present in the bone (Petchey and Higham, 2000). BB%C may also be used as a contamination indicator when expected BB%C values are subtracted from actual BB%C values (Bocherens *et al.*, 2005). Expected BB%C values used here were derived from the 31 modern Pacific cod skeletal elements using linear regression analysis. Expected values were obtained by entering the BB%N content (Table 7.5) into an empirical formula established by Bocherens *et al.*(2005:562) for mammals that has been adapted here for Pacific cod: [expected BB%C=(BB%N x 2.528) + 1.478], where (2.528) reflects the fraction of bulk bone carbon associated with bone protein (organic portion), and (1.478) represents the fraction of bulk bone carbon associated with bone mineral. However, because diagenic carbon loss solely affects the bone protein fraction, a correction factor of 0.5% was added to each expected BB%C value. The difference between expected and actual BB%C values was then used to quantify the level of carbon-rich

contaminants that entered the bone from the burial environment (Bocherens *et al.*, 2005) (Table 7.9).

Table 7.9. Actual and expected BB%C and associated carbon contamination proxy values of 31 modern Pacific cod samples.

Sample Number	Actual BB%C	Expected BB%C [%C= (%N x 2.528) + 1.478]	Actual-Expected BB%C (carbon contamination)
PC-01	14.20	14.47	-0.27
PC-02	14.29	14.35	-0.06
PC-03	14.61	14.78	-0.17
PC-04	14.40	14.85	-0.45
PC-05	14.80	14.90	-0.10
PC-06	13.59	13.61	-0.02
PC-07	13.80	13.97	-0.17
PC-08	14.32	14.29	0.03
PC-09	14.88	14.70	0.18
PC-10	14.88	14.83	0.05
PC-11	14.44	14.09	0.35
PC-12	13.91	13.81	0.10
PC-13	14.55	14.75	-0.02
PC-14	14.54	14.55	-0.01
PC-15	14.72	14.57	0.15
PC-16	4.76	5.47	-0.87
PC-17	14.48	14.27	0.21
PC-18	14.52	14.42	0.10
PC-19	14.40	14.35	0.05
PC-20	14.63	14.55	0.08
PC-21	14.43	14.47	-0.04
PC-22	14.61	14.80	-0.19
PC-23	14.39	14.40	-0.01
PC-24	14.30	14.19	0.11
PC-25	12.69	12.88	-0.19
PC-26	15.75	15.61	0.14
PC-27	14.26	14.29	-0.03
PC-28	14.65	14.47	0.18
PC-29	14.21	14.27	-0.06
PC-30	14.70	14.50	0.20
PC-31	14.23	14.19	0.04
Mean	**14.09**	**14.12**	**-0.02**

Expected and actual BB%C values of modern and Mink Island skeletal elements are presented in Table 7.10 and Figure 7.13. The actual BB%C values are the same values presented in Table 7.8 and Figure 7.9. When plotted together it is possible to determine how the level of contamination by carbon rich sources changes over time. Because the linear regression formula was established using the modern Pacific cod samples (Table 7.9), the actual and expected BB%C values are the same. The Upper Midden samples are less contaminated than the Lower Midden samples. Based on these data, the Pacific cod skeletal elements became more contaminated over time by carbon-rich sources despite losing overall carbon content. In the next section, the expected BB%C content is subtracted from the actual BB%C content to obtain proxy carbon contamination values (see Table 7.9). One-way ANOVA is then used to determine if significant differences in carbon contamination values exist among BVD, completeness %, and radiocarbon year BP categories.

Table 7.10. Carbon contamination (actual minus expected BB%C) evaluation of Mink Island Pacific cod samples.

Bulk Bone Percent Carbon Evaluation					
Calibrated Radiocarbon Years BP (2 Sig.)	Cultural Affiliation	Number of Samples Analyzed	Mean Bulk Bone Percent Carbon		Difference Between Mean Actual Vs. Expected Values
			Expected Values	Actual Values	
0	Modern	31	14.12	14.09	-0.03
<535	Thule	6	9.11	11.85	2.74
535	Thule	6	8.48	10.93	2.45
735	Thule	3	8.65	10.90	2.25
745	Thule	3	8.94	10.65	1.71
910	Thule/Norton/Kachemak	6	9.07	11.35	2.28
915	Thule/Norton/Kachemak	6	8.37	10.83	2.46
1510	Norton/Kachemak	3	8.14	10.12	1.98
5047	Ocean Bay II	26	6.09	9.18	3.09
5340	Ocean Bay I	13	5.00	8.82	3.82
All Periods	**All Traditions**	**103**	**9.21**	**11.21**	**2.00**

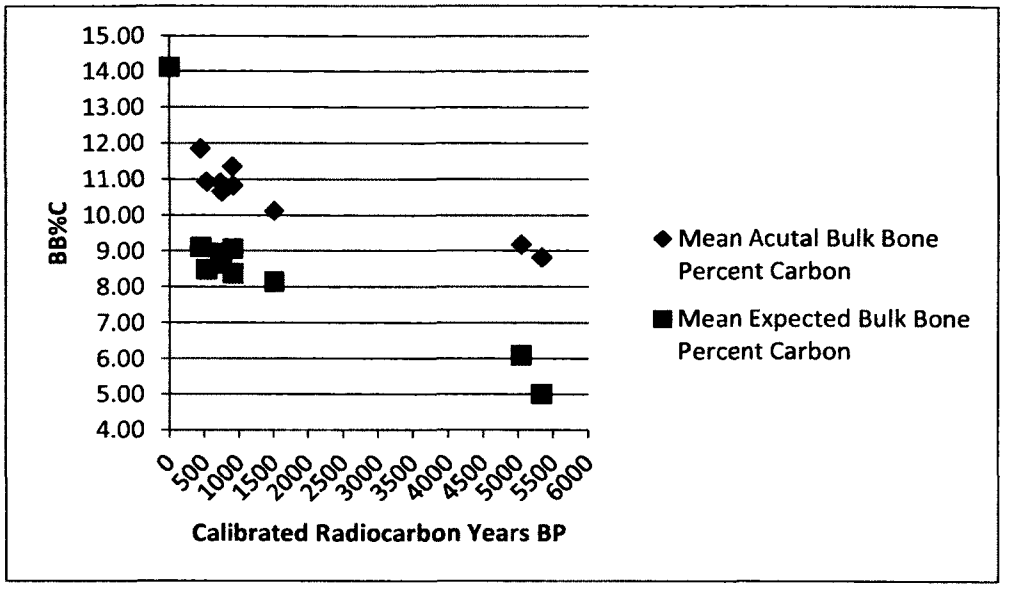


Figure 7.13. Actual versus expected mean BB%C values of modern and Mink Island pacific cod samples.

Carbon Contamination

One-way ANOVA statistical analysis was used to determine that carbon contamination differs significantly (negatively) among BVD categories (F= 5.27; *df*= 5, 66, p=.000). Dentaries, the densest Pacific cod skeletal elements, possess the highest mean carbon contamination (M=3.77, 95% CI [2.92, 4.61]) and SD values (Figure 7.14). Hyomandibulars, the least dense skeletal elements, possess the lowest carbon contamination (M=1.85, 95% CI [1.40, 2.30]) and SD values. This pattern is opposite of what would be expected if increased BVD was linked with decreased contamination potential. As with the preservation pattern, the decreased carbon contamination pattern associated with the hyomandibular may be because they were buried for a shorter period. This phenomenon is explored in a later section.

One-way ANOVA statistical analysis was also used to determine that carbon contamination is linked to retention of cortical bone integrity; contamination differs significantly among completeness % categories (F= 3.88; *df*= 9, 62; p=.001). The most complete skeletal elements tend to be the least contaminated skeletal elements (Figure 7.15). As fragmentation

increases, contamination by carbon rich sources (i.e. humic substances) tends to increase. The high degree of overlap seen with the SD values is indicative of another factor affecting carbon contamination among the Mink Island samples. The especially high SD value associated with the 10%-complete skeletal elements (M=4.11, 95% CI [2.71, 5.52]) is skewed by a single dentary that was highly contaminated by carbon-rich sources (actual minus expected BB%C =8.19).

To explore if the burial duration affected carbon contamination potential, contamination values were compared to radiocarbon years BP. Results of one-way ANOVA statistical analysis are that there are significant differences (F= 5.12; *df*= 8, 63; p=.000) among the radiocarbon year BP categories (Figure 7.16). The modern skeletal elements contain zero carbon contamination and, therefore, are significantly less contaminated than skeletal elements from both the Upper Midden and the Lower Midden contexts (Figure 7.16). Tukey post-hoc comparisons indicate that except for the Ocean Bay I assemblage (5340 cal. BP) (M=3.82, 95% CI [2.96, 4.67]), there is not a significant difference in carbon contamination values between the skeletal elements from the Upper and Lower Midden contexts (p>.05). The associated SD value is also high among the Ocean Bay I assemblage, which is consistent with a high degree of variability in contamination levels during this period. This pattern supports the conclusion that Ocean Bay I skeletal elements were subjected to increased diagenic agent action (compaction and leaching). As Figure 7.16 demonstrates, skeletal elements from the Upper Midden context (<535 – 1510 cal. BP) possess a unique signature; carbon contamination decreases over time. If carbon contamination was solely linked with burial duration, carbon contamination should increase over time. Therefore, some other factor/s besides the burial duration is affecting overall contamination potential.

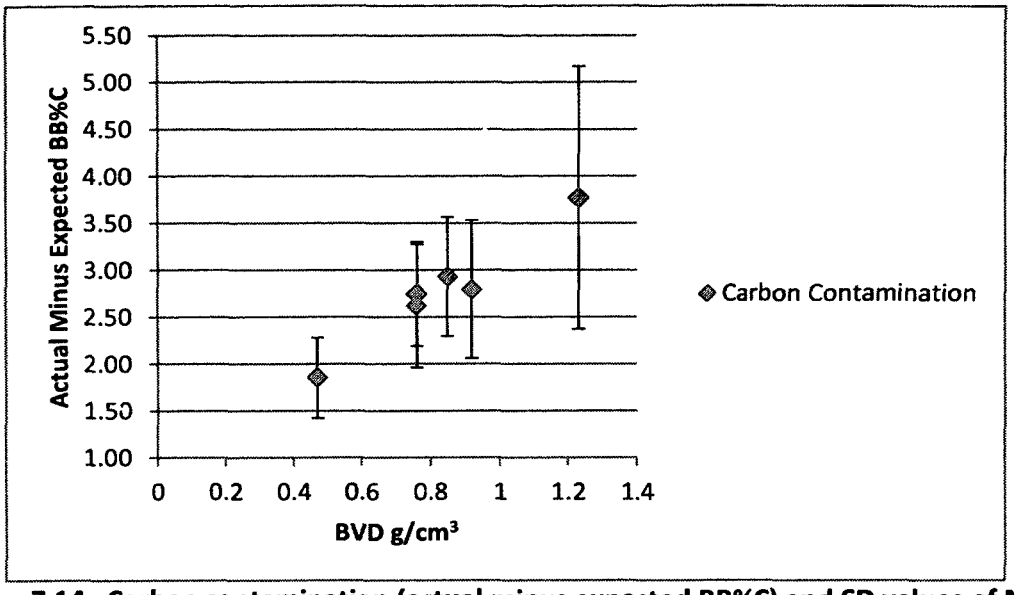


Figure 7.14. Carbon contamination (actual minus expected BB%C) and SD values of Mink Island Pacific cod samples aggregated by BVD values.

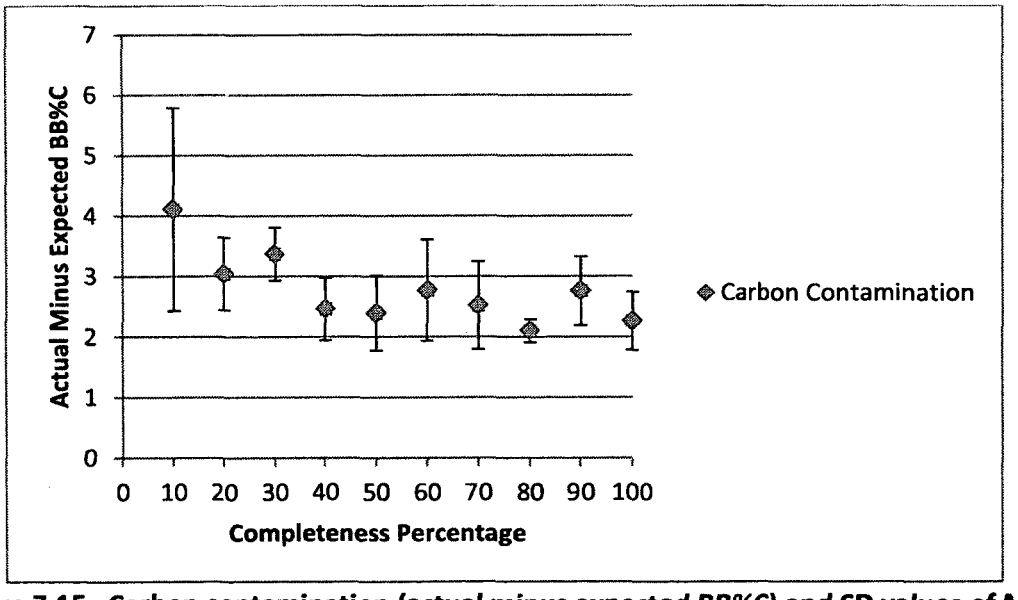


Figure 7.15. Carbon contamination (actual minus expected BB%C) and SD values of Mink Island Pacific cod samples aggregated by completeness %.

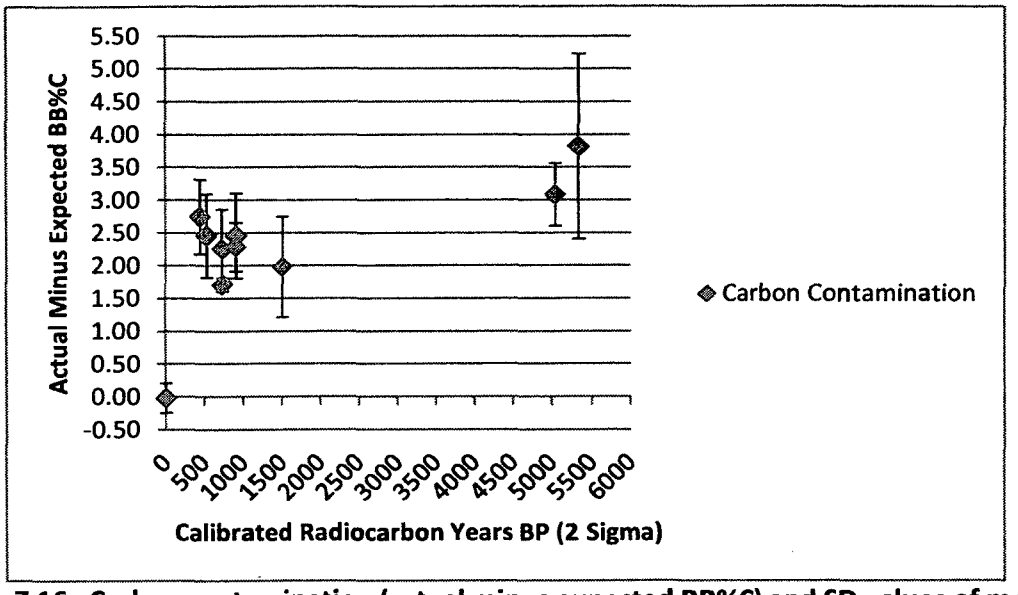


Figure 7.16. Carbon contamination (actual minus expected BB%C) and SD values of modern and Mink Island Pacific cod samples aggregated by calibrated radiocarbon years BP.

Contamination Conclusions

The results of carbon contamination evaluations are combined here to reveal the factor/s affecting the contamination potential of the 72 Mink Island Pacific cod skeletal elements. The contamination values of 31 modern pacific cod dentaries that were presented in Table 7.9, establish baseline values. Carbon contamination differs significantly (negatively) among BVD categories (Table 7.11). The least dense skeletal elements are the least contaminated, which is opposite of what would be expected if decreased BVD augmented contamination potential. Therefore, contamination potential is linked with something other than BVD.

Table 7.11. Carbon contamination evaluation (actual minus expected BB%C) of Mink Island Pacific cod samples aggregated by BVD. BVD values were obtained from Smith (2008: Table 12, pg. 68).

Carbon Contamination Evaluation				
Pacific cod (*Gadus macrocephalus*)	**Number of Samples Analyzed**	**BVD g/cm^3**	**Actual Minus Expected BB%C**	**Standard Deviation**
Dentary	13	1.23	3.77	1.40
Maxilla	12	0.92	2.79	0.74
Vomer	14	0.85	2.93	0.64
Quadrate	13	0.76	2.75	0.56
Atlas Vertebra	13	0.76	2.62	0.66
Hyomandibular	6	0.47	1.85	0.43
All Elements	**71**	**N/A**	**2.88**	**0.94**

Carbon contamination differs significantly among skeletal element completeness % categories (Table 7.12). As skeletal elements become more fragmentary, carbon contamination increases. After the exterior cortical bone layer of the bone loses its integrity, it becomes increasingly vulnerable to the effects of diagenic agents. The interior, trabecular portion of the bone acts as a sponge that absorbs water-soluble contaminants as the matrix fluctuates between wet and dry cycles. Solid contaminants also become packed into interior pore spaces of the bone without the aid of water. As long as the exterior cortical bone retains its integrity, contamination remains minimal. However, if the cortical bone is compromised in any way, contamination increases.

Table 7.12. Carbon contamination evaluation (actual minus expected BB%C) of Mink Island Pacific cod samples aggregated by completeness %.

Carbon Contamination Evaluation			
Completeness Percentage	**Number of Samples Analyzed**	**Actual Minus Expected BB%C (Carbon Contamination)**	**Standard Deviation**
10	8	4.11	1.68
20	11	3.04	0.6
30	8	3.37	0.44
40	5	2.46	0.52
50	5	2.39	0.62
60	12	2.77	0.84
70	4	2.52	0.73
80	5	2.1	0.19
90	8	2.76	0.57
100	6	2.26	0.48
Total	**72**	**2.88**	**0.94**

Carbon contamination also differs significantly among radiocarbon year BP categories. Carbon contamination increase as the burial duration increases (Table 7.13). There is a significant difference ($p<.01$) in carbon contamination between the modern skeletal elements and the Upper and Lower Midden skeletal elements. Except for the Ocean Bay I assemblage (5340 cal. BP) there is not a significant difference ($p<.05$) in carbon contamination between the Upper and Lower Midden assemblages. The Ocean Bay I skeletal elements are significantly ($p<.05$) more contaminated than the remaining assemblages. Because skeletal elements belonging to the Ocean Bay I assemblage were at the bottom of the shell midden, they were affected by soil compaction to a greater extent than skeletal elements at the top of the midden. As soil compaction affects cortical bone integrity (see Chapter 5), Ocean Bay I skeletal elements tend to be more fragmented than other Mink Island skeletal elements (see Chapter 6). Increased fragmentation resulted in increased contamination because of rainwater and groundwater leaching. As rainwater percolated through the shell midden, water-soluble carbon contaminants travelled through the matrix until they met resistance and settled among the lowest levels of the midden. As the shell midden dried out, carbon-rich contaminants were

absorbed into the open pore spaces of fragmented bones. Similarly, as groundwater inundation filtered up through the midden, it transferred the water-soluble carbon contaminants up through the shell midden until gravity prevented further upward movement and redeposited the contaminants among the lowest midden levels to become absorbed into the open pore spaces of the fragmented bones. Therefore, the large difference in carbon contamination and associated standard deviation values between the Ocean Bay I (5340 cal. BP) and the Ocean Bay II (5047 cal. BP) assemblages is expected, and is indicative of differential diagenic agent action.

Proximity to the surface-level of the shell midden context also affected carbon contamination potential. Skeletal elements positioned near the surface were trampled to a greater extent than skeletal elements elsewhere. As trampling affects cortical bone integrity (see Chapter 5), near-surface skeletal elements tend to be more fragmented than other skeletal elements (see Chapter 6). Increased fragmentation amplified contamination as carbon-rich contaminants from the soil humus layer entered open pore spaces. As the distance from the soil humus layer increased, carbon contamination decreased.

Table 7.13. Carbon contamination evaluation (actual minus expected BB%C) of modern and Mink Island Pacific cod samples aggregated by calibrated radiocarbon years BP.

Carbon Contamination Evaluation				
Calibrated Radiocarbon Years BP (2 Sig.)	**Cultural Affiliation**	**Number of Samples Analyzed**	**Actual Minus Expected BB%C**	**Standard Deviation**
0	Modern	31	-0.02	0.23
<535	Thule	6	2.74	0.57
535	Thule	6	2.45	0.64
735	Thule	3	2.25	0.60
745	Thule	3	1.71	0.10
910	Thule/Norton/Kachemak	6	2.28	0.37
915	Thule/Norton/Kachemak	6	2.45	0.65
1510	Norton/Kachemak	3	1.98	0.77
5047	Ocean Bay II	25	3.08	0.48
5340	Ocean Bay I	13	3.82	1.41
All Periods	**All Traditions**	**102**	**2.00**	**1.55**

Applications for Stable Isotope ($\delta^{13}C$, $\delta^{15}N$) Data

The results of the preservation and contamination assessments of the modern and Mink Island Pacific cod samples may be used to make informed decisions as to which skeletal element is best suited for stable isotope ($\delta^{13}C$, $\delta^{15}N$) analysis. Additionally, the data may be used to validate the modified Bell *et al.* (2001) stable isotope pretreatment method for use with archaeological fish bones. Although these research questions are useful for establishing appropriate fish-specific methods, they say nothing about why one would want to reconstruct $\delta^{13}C$ and $\delta^{15}N$ values. Reconstructing temporal changes in ecosystem structure and function is one application, and is briefly described in the following paragraphs.

Fish bones from shell midden deposits represent a unique way to reconstruct changes in past marine ecosystem structure and function. The fish bone/shell midden deposits are similar to other stratigraphic deposits such as foraminifera in deep-sea sediment cores, water and atmosphere in ice cores, and pollen in lake sediment cores in that they are archives of changing environmental conditions (Hedges *et al.*, 2004). Bones are especially useful for environmental/climatic reconstructions because they represent more biologically averaged temporal variations as compared to plants, and therefore, produce a less noisy signal (Hedges *et al.*, 2004). As long as there is a continuous record over time, bone collagen is an excellent paleoenvironmental archive.

Laboratory (e.g. Ambrose and Norr, 1992) and field data (e.g. DeNiro and Epstein, 1978) demonstrate a direct relationship between dietary and bone collagen $\delta^{13}C$ and $\delta^{15}N$ values. Bone collagen nitrogen isotope values are derived from ingested protein and are related to the $\delta^{15}N$ value of the diet. The $\delta^{15}N$ of the consumer is between 3‰ and 5‰ enriched over the diet (Ambrose, 2000; DeNiro and Epstein, 1978; Schoeninger and DeNiro, 1984). Bone collagen carbon isotope values may be derived from a variety of sources since non-essential amino acids in proteins may be synthesized from carbohydrates. Although, it is generally assumed that $\delta^{13}C$ values are mainly registering carbon from dietary protein (Hedges *et al.*, 2004). The $\delta^{13}C$ of the consumer is about 1‰ enriched over the diet (Fry and Sherr 1984; Minagawa and Wada 1984). Reasons for the enrichment of $\delta^{13}C$ and $\delta^{15}N$ values are not well understood but may be related to digestive processes (Schoeninger and DeNiro, 1984).

Fish $\delta^{15}N$ values are reliable indicators of trophic levels in marine systems (Dickson, 1986; Fry, 1988; Wada, 1987; Wada *et al.*, 1987). In a study of the food web structure of Georges Banks, Fry (1988: 1184) discovered that fish were enriched in ^{15}N as compared to their diets by 3.4-3.8‰. Fish $\delta^{13}C$ values show 1.5-1.6‰ enrichment as compared to their diets (Fry, 1988). Although there was a correlation between $\delta^{13}C$ values and trophic status, they were not as reliable as $\delta^{15}N$ values (Fry, 1988). Most of the $\delta^{13}C$ increased occurred in the early stages of the food web at the level of particulate-feeding invertebrates such as scallops and isopods (Fry, 1988). Conversely, ^{15}N increases were much more standardized with piscivorous fish having higher $\delta^{15}N$ values than planktivorous fish, and planktivorous fish having higher $\delta^{15}N$ values than invertebrates (Fry, 1988). Fry (1988: 1186) suggests $\delta^{13}C$ values are linked to phytoplankton food resources with differing isotopic compositions, and indicate primary productivity and climatic conditions. Van Klinken and Hedges (1995) also suggest that there is a correlation between $\delta^{13}C$ values and climate. They demonstrated that bone collagen and plant materials varied in analogous ways with such climatic parameters as July sunshine or July temperatures. Therefore, $\delta^{13}C$ values may be used as a proxy indicator of climate-driven changes in primary productivity.

Primary productivity affects the entire food web structure in a marine system (Schoeninger and DeNiro, 1984). Increased primary productivity provides more food at the base of the food web (e.g. phytoplankton and particulate organic matter), which is transmitted up the food web from invertebrates, planktivorous fish, opportunistic generalists, to piscivorous fish (Fry, 1988). With increased primary productivity, indicated by higher $\delta^{13}C$ values, there should be a decrease in taxa-specific trophic status, as indicated by $\delta^{15}N$ values (Schoeninger and DeNiro, 1984; Fry, 1988). Trophic status decreases because with increased primary productivity there is more food available for the entire marine system. With increased food availability, fish tend to eat a more varied diet with a higher percentage of lower trophic level foods. Conversely, with decreased primary productivity, there should be an increase in taxa-specific trophic status (Schoeninger and DeNiro, 1984). With lower primary productivity, food becomes scarce throughout the system and fish are forced to specialize on just a few food sources. This specialization results in higher trophic status (Schoeninger and DeNiro, 1984). Therefore, $\delta^{13}C$

and $\delta^{15}N$ values should mirror each other (inversely related) over time; any temporal changes may indicate fluctuations in marine ecosystem structure and function.

Pacific Cod Skeletal Elements and Stable Isotope Analysis

With the establishment that $\delta^{13}C$ and $\delta^{15}N$ values may be used to reconstruct ecosystem structure and function, the discussion returns to its methodological focus. In the following section, preservation and contamination indicators are combined to identify the best Pacific cod skeletal element for stable isotope ($\delta^{13}C$, $\delta^{15}N$) analysis. Evaluations incorporate data limitations associated with paleoenvironmental reconstructions that use stable isotopic methods.

Research Question 4: Is the Pacific cod dentary the best preserved (physical appearance, BB%N, BB%C, and % collagen yield) and least contaminated (expected versus actual BB%C) skeletal element (possess the lowest average ranking), and therefore the most appropriate skeletal element to use for stable isotope ($\delta^{13}C$, $\delta^{15}N$) analysis?

Null Hypothesis 4: Pacific cod dentaries do not possess the lowest average preservation/ contamination ranking, and therefore, they are not suitable for stable isotope analysis. H_o: $p \geq .05$

Alternate Hypothesis 4: Pacific cod dentaries possess the lowest average preservation/ contamination ranking, and therefore, they are suitable for stable isotope analysis. H_a: $P < .05$

Results:

Multiple proxy indicators are used in this section to determine if the Pacific cod dentary is the most suitable skeletal element for stable isotope ($\delta^{13}C$, $\delta^{15}N$) analysis. The skeletal elements analyzed (e.g. hyomandibular, quadrate, atlas vertebra, dentary, maxilla, and vomer) are ranked from most suitable (e.g. 1) to least suitable (e.g. 6) using the following proxy

indicators: BVD, abundance (MAU), mean completeness %, physical appearance class assessment, BB%N, BB%C, % collagen yield, and carbon contamination. Pacific cod skeletal elements with the lowest average rankings are selected as the most suitable for stable isotopic analysis.

Results of the rank assessment (preservation and contamination) are presented in Table 7.14. The hyomandibular has the lowest average ranking (2.25), which on the surface-level suggests that it is the most suitable skeletal element for stable isotope analysis. However, because the hyomandibular was not recovered from the Lower Midden contexts (e.g. 5047 and 5340 cal. BP), and there are significant differences in preservation and contamination values among the radiocarbon years BP categories (Tables 7.8 and 7.13), these data are problematic. Additional hyomandibular specimens belonging to the Lower Midden assemblages need to be analyzed before conclusive statements may be made concerning its suitability for stable isotope analysis. The hyomandibular's low average ranking is most likely related to its low completeness % ranking. Because hyomandibulars have a low BVD value (0.47 g/cm^3) and lack robusticity (see Chapter 6), they tend to become too fragmented to identify beyond class quickly compared to many other skeletal elements. Those hyomandibulars that remained relatively complete, tend to be better preserved and less contaminated.

Another problem associated with using the hyomandibular for stable isotopic research is that individual Pacific cod hyomandibular measurements have not been connected with fork length measurements (e.g. Orchard, 2003) using linear regression analysis. Therefore, it is exceedingly difficult to reconstruct the age structure of Pacific cod specimens from individual hyomandibular measurements. Because Pacific cod feed at different trophic levels depending on their ages (e.g. Fry, 1988), it is essential to be able to reconstruct their age (e.g. fork length) when interpreting $\delta^{15}N$ values. Therefore, the hyomandibular is not well suited for stable isotopic research in those instances where $\delta^{15}N$ values (e.g. trophic status) are used with $\delta^{13}C$ values (e.g. primary productivity) to reconstruct paleoenvironmental conditions.

The dentary is ranked second (rank=3.25). Because the dentaries analyzed here were recovered from the Lower Midden and Upper Midden contexts, the results are not biased by differences in burial duration. Therefore, the Pacific cod dentary is ideally suited for stable isotope analysis. Pacific cod dentaries have been correlated with fork length measurements

(e.g. Orchard, 2003), and, therefore, the individual age class may be reconstructed using the linear regression analysis method. Because age class may be inferred, $\delta^{15}N$ values may be used to assess trophic structure (Fry, 1988).

While dentaries are ideally suited for stable isotope analysis, a pattern is visible among the dentary rank value that needs to be addressed (Table 7.14). Dentaries possess the highest contamination value (6), and possess BB%N, % collagen yield, and completeness %values that are among the highest (5, 4, and 4, respectively). This pattern indicates that the dentary is highly affected by fragmentation. As contamination, % collagen yield, and BB%N values differ significantly ($p<.05$) among completeness % categories (e.g. fragmentation), only the most complete dentaries should be chosen for stable isotope analysis. Complete, or nearly complete dentaries, therefore, possess the highest potential to produce useful results to reconstruct ecosystem structure and function.

The quadrate and the atlas vertebra are the third most suitable skeletal elements for stable isotope analysis (ranking = 3.31). The quadrate and atlas vertebra possess equal average rankings but different individual proxy-indicator values (except BVD values) (Table 7.14). The quadrate is more abundant (MAU), has higher BB%N values, and has higher BB%C values. Whereas the atlas vertebra has a higher completeness %, appears to be better preserved, and is less contaminated. Linear regression analysis has been completed for Pacific cod quadrates and atlas vertebrae (Orchard, 2003), and they are both suitable for paleoenvironmental reconstructions. Although quadrates tend to be slightly better preserved (higher BB%N and BB%C values), the deciding factor will be abundance values.

The vomer is ranked in fifth place and has an average ranking of 4.25. The vomer has the highest BB%N, BB%C, and % collagen yield rankings (6) coupled with the second highest carbon contamination and completeness % rankings (5), and therefore, it is not well suited for stable isotope analysis (Table 7.14). Because abundance and physical appearance does not significantly affect preservation and contamination potential, the lower rankings associated with these proxy data (1 and 2, respectively) does not enhance the vomers' suitability for stable isotope analysis. Vomer size corresponds to fork length (Orchard, 2003), so $\delta^{15}N$ values can be linked with fish age structure. However, the preservation and contamination issues diminish the

likelihood that the vomer would produce stable isotope results that accurately reflect trophic status ($\delta^{15}N$) and primary productivity (e.g. $\delta^{13}C$).

The maxilla is ranked sixth and has an average ranking of 4.5 (Table 7.14). The maxilla has the highest completeness % and physical appearance rankings (6), and the second highest abundance, BB%C, and % collagen yield rankings (5). The remaining rankings are also high, therefore the maxilla is not well suited for stable isotope analysis. The largest problem associated with the maxilla is that it tends to be highly fragmented, and therefore is affected by preservation and contamination problems. Linear regression analysis has not been completed for the maxilla (Orchard, 2003), so it is difficult to link $\delta^{15}N$ values with age structure. Therefore, stable isotope values derived from maxillae would not be as accurate as those derived from dentaries, quadrates, and atlas vertebrae.

The multi-proxy preservation and contamination data indicate that dentaries are best suited for stable isotope analysis. Dentaries have the lowest average ranking of those Pacific cod skeletal elements whose fork length may be reconstructed from individual measurements via linear regression analysis (e.g. Orchard, 2003); therefore, the null hypothesis may be rejected. Quadrates and atlas vertebrae are second most likely to produce accurate stable isotopic results. As the vomer and the maxilla are plagued with preservation and contamination problems and individual fork lengths cannot be reconstructed via linear regression analysis, they are not suited for stable isotopic analysis.

Table 7.14. Pacific cod preservation and contamination RANK evaluations of Mink Island samples. BVD values are from Smith (2008: Table 12, Pp. 68).

	Pacific cod (*Gadus macrpcephalus*) RANK								
Skeletal Element	BVD (g/cm^3)	Abundance (MAU)	Completeness Percentage	Physical Appearance	BB%N	BB%C	Collagen Yield	Carbon Contamination	Average Ranking
Hyomandibular	6	6	1	1	1	1	1	1	2.25
Dentary	1	2	4	2	5	2	4	6	3.25
Atlas Vertebra	4.5	4	2	4	4	4	2	2	3.31
Quadrate	4.5	3	3	5	2	3	3	3	3.31
Vomer	3	1	5	2	6	6	6	5	4.25
Maxilla	2	5	6	6	3	5	5	4	4.5

Pacific Cod Skeletal Element Sample Selection Guidelines

By following the sample selection guidelines below, stable isotope values will be more likely to reflect ecosystem structure and function rather than differences in preservation and contamination.

1. Select skeletal elements that are as complete as possible (at least 30% complete) (Figures 7.17 and 7.18).

2. Choose skeletal elements that are un-burned (organic char affects $\delta^{13}C$ values) (Brain and Sillen, 1984: 464).

3. Pick skeletal elements that have smooth and intact cortical bone (elements that are chalky/woody in appearance indicate that the cortical bone has lost its integrity) (e.g. Petchey and Higham, 2000).

4. Use only those skeletal elements that have been analyzed using linear regression analysis, where the relationship between specific skeletal element measurements and fork length are known (e.g. Orchard, 2003). Pacific cod feed at different trophic levels depending on their age, therefore $\delta^{15}N$ values differ accordingly (Fry, 1988).

5. Dentaries that meet the previous guidelines (1-4) possess the highest probability of producing stable isotope values that are free from preservation and contamination biases.

Figure 7.17. Mostly intact Pacific cod dentary from the Mink Island site. Photo by Rhea Hood, National Park Service.

Figure 7.18. Fragmented Pacific cod dentary (20% complete), too fragmented to provide accurate Stable Isotope ($\delta^{13}C$ and $\delta^{15}N$) values. Photo by Rhea Hood, National Park Service.

Suitability of the Modified Bell *et al.* (2001) Pretreatment Method for Use on Archaeological Fish bones

The suitability of the modified Bell *et al.* (2001) pretreatment method for use with archaeological fish bones evaluated in this section. The discussion begins with a description of the pretreatment method. The ways to assess the quality of individual stable isotope values are also described. Results ($\delta^{13}C$, $\delta^{15}N$) and associated quality control indicators (% collagen yield, %C by weight, %N by weight, and atomic C: N value), are separated by BVD (skeletal element), completeness %, and the burial duration to determine if values differ significantly among categories.

Research Question 5: Do quality control indicators (%collagen yield, %C by weight, %N by weight, and atomic C: N) validate the modified Bell *et al.* (2001) method for archaeological fish bones?

Null Hypothesis 5: Quality control indicators (%collagen yield, %C by weight, %N by weight, and atomic C: N) do not validate the modified Bell *et al.* (2001) for archaeological fish bones. H_o: $p \geq .05$.

Alternate Hypothesis 5: Quality control indicators (%collagen yield, %C by weight, %N by weight, and atomic C: N) validate the modified Bell *et al.* (2001) method for archaeological fish bones. H_a: $p < .05$.

Modified Bell et al. (2001) Stable Isotope ($\delta^{13}C$, $\delta^{15}N$) Pretreatment Assessment

The goal of stable isotope pretreatment is to remove the mineral portion of the bone and contaminants (e.g. lipids, humic acids, fulvic acids, humins, sediments etc.) to obtain pure "collagen" (Ambrose, 1990; Gillespie, 1989). Pretreatment methods lack standardization, and some methods are better suited than others for archaeological fish bones. Because fish bones have a structural (e.g. mineralization, collagen fibril packing, and BVD) and chemical composition (e.g. amino acid sequence, lipid content, and protein content) that is different from mammals or birds, they must be treated differently during stable isotope pretreatment (Szpak, 2011) (see Chapter 5). Stable isotope pretreatment methods that were designed for use with modern mammals may not be appropriate for archaeological fish bones.

The Bell *et al.* (2001) pretreatment method was chosen because it uses weak acid concentrations (0.5 M HCl) for short periods (60 minutes), it does not use heat to drive collagen into solution, and it uses hexane: isopropanol, a less harsh solvent to extract lipids. Because stable isotope researchers often employ different pretreatment methods, and inclusions and omissions of steps coupled with differences in chemicals used and their strengths have the potential to affect $\delta^{13}C$ and $\delta^{15}N$ values, some of those methods are discussed in conjunction with the Bell *et al.*(2001) method below.

Some researchers use bone chunks while others use bone powder (Bell *et al.*, 2001). The modified Bell *et al.* (2001) method uses bone powder. Bone chunks are easier to handle, but require additional processing time because they possess less exposed surface area, which results in slower chemical reactions. Bone powder is more difficult to handle because it requires a centrifuge to separate the bone from the liquid portion, but chemical reactions occur in a fraction of the time required by the bone chunk method and this difficulty is outweighed by processing speed.

Because lipids may affect $\delta^{13}C$ values (Radin, 1981; Szpak, 2011), they must be removed during the stable isotope pretreatment process. Some solvent mixtures (e.g. chloroform: methanol) are highly toxic and may remove proteins as well as lipids (Liden *et al.*, 1995; Radin, 1981). Therefore, it is important to limit solvent exposure (Radin, 1981; Szpak, 2011). The modified Bell *et al.* (2001) method uses a mixture of hexane: isopropanol with a ratio of 3:2 for a short duration (5 minutes). This mixture is less toxic than others, removing small amounts of non-lipid materials (Radin, 1981).

After lipids are successfully removed from the bone powder, the mineral portion and the acid soluble contaminants (e.g. fulvic acids) are dissolved using the modified Bell *et al.* (2001) method. The treatment process beings with the application of 1.5 ml of 0.5 M hydrochloric acid (HCl) during three 10-minute intervals for a total of 30 minutes. The HCl is centrifuged and poured off after ten minutes and fresh 1.5 ml of 0.5 HCl is added to allow for complete demineralization. This process is completed a second time for an overall processing time of 60 minutes. It is during this step that the Bell *et al.*(2001) method is modified; the method employed here uses 0.5M HCl rather than 0.1M HCl concentrations to speed up reaction times. After the bone powder is processed, the remaining HCl is poured off and the samples are rinsed three times using ultrapure water.

During the next phase, the samples are treated with alkali to remove organic contaminants (e.g. humic acids). Alkali treatments may degrade collagen, so exposure is limited during this step (Chisholm *et al.*, 1993; Katzenberg, 2000). The modified Bell *et al.* (2001) method uses 1.5 ml of 0.1 M sodium hydroxide (NaOH) for a 10-minute treatment. Afterwards, the samples are centrifuged and the NaOH is poured off and the samples are rinsed three times using ultrapure water.

Once the bone samples have received the hexane: isopropanol, HCl, and NaOH treatments, it is necessary to decide whether to gelatinize the bone collagen. The modified Bell *et al.* (2001) method skips this step, but other methods gelatinize bones (e.g. Ambrose, 1990; Longin, 1971; etc.). Gelatinization is achieved by heating collagen in a weak acid, 0.001 M HCl (Hu *et al.*, 2006). This causes the collagen to denature, and break bonds with contaminants that persisted after acid and alkali treatments (e.g. humins) (Longin, 1971; Dubach and Mehta, 1963; van Klinken and Hedges, 1995). The "collagen" goes into solution, while the contaminants fall as solids to the bottom of the test tube (Longin, 1971). The "collagen" may be separated via centrifugation (Longin, 1971; van Klinken and Mook, 1990) or by filtration using a coarse filter (Ambrose, 1990; Schoeninger and DeNiro, 1984). The modified Bell *et al.* (2001) method skips this step to avoid "unnecessary complications." (Lee-Thorp, 1989:52). Schoeninger *et al.* (1989) suggests non-gelatinized samples may produce extracts more similar to bone collagen than gelatinized samples. The main issue with gelatinization is the potential for excessive heat to alter the amino acid structure, and may affect $\delta^{13}C$ and $\delta^{15}N$ values (van Klinken and Mook, 1990). Because the modified Bell *et al.* (2001) method avoids this step, particulate organic matter, humic acids, fulvic acids, and humins can remain in the test tubes (Ambrose, 1993; Dubach and Mehta, 1963; Longin, 1971; van Klinken and Mook, 1990). Therefore, contamination can be an issue. By avoiding the bottom portion of the sample, most of these contaminates may be circumvented. Quality control indicators (%C by weight, %N by weight, atomic C: N values) may be used to assess sample quality (van Klinken, 1999).

Afterwards, the samples are freeze dried for twenty-four hours and they are ready to be submitted to a stable isotope facility. The samples prepared here were weighed, and submitted to the Alaska Stable Isotope Facility for stable carbon ($\delta^{13}C$) and stable nitrogen ($\delta^{15}N$) analysis. Isotope samples were run using an elemental analyzer isotope ratio mass spectrometer (EA IRMS) continuous flow system using international standards. The $\delta^{13}C$ values were standardized relative to Vienna PeeDeeBelmnite (VPDB) and $\delta^{15}N$ values were standardized relative to air.

Assessing Quality of Stable Isotope ($\delta^{13}C$, $\delta^{15}N$) Values

Stable isotope values and the raw data accompanying and derived from the values (% collagen yield, %C by weight, %N by weight, and atomic C: N value) may be used to assess preservation and contamination levels (Ambrose, 1993; van Klinken, 1999). Acceptable ranges of stable isotope values and associated quality control indicators have been established for typical modern and archaeological mammal bones (c.f. Ambrose, 1990, 1993; Bell *et al.*, 2001; Kennedy, 1988; van Klinken, 1999). Typical modern mammal bone collagen yield should be between 20 and 30% (Kennedy, 1988), %C by weight should be between 42.20 and 50.51%, %N by weight should be between 15.35 and 18.37% (Ambrose, 1993; Kennedy, 1988), and atomic C: N value [(%C/%N) x 1.167] should be 3.2 (Ambrose, 1993).

Acceptable stable isotope value ranges and quality control indicators have not been established for fish bones. Although quality control indicators may be derived from the amino acid sequence, which has been worked out from the DNA sequence of Atlantic cod (*Gadus morhua*) (Arnesen and Gildberg, 2006) (see Appendix F for a description of how figures were calculated). Based on modern Atlantic cod bone, % C by weight should be between 41.04%-49.22%, %N by weight should be between 15.61% and 18.72%, and the atomic C: N value should be 3.07 (Arnesen and Gildberg, 2006). Quality control indicators established for typical mammal bone are quite different from those for cod bones as derived from the amino acid sequence. These differences are largely because of the structural and functional differences between mammal and fish bones (see Chapter 5). Regardless of these differences, the steps to assess preservation and contamination are the same. Quality control indicators that accompany or are derived from the stable isotope data are compared to typical values. Any values that are outside of the typical range are discarded.

Percent collagen yield is a measure of the bone "collagen" remaining in the skeletal element. "Collagen" is in quotation marks because bone collagen extracted using stable isotope pretreatment methods consists of the original carbon and nitrogen from protein as well as hydrogen and oxygen, which are attached to polypeptide fragments and free amino acids (Pfeiffer and Varney, 2000). Hydrogen and oxygen are added to the polypeptide fragments and free amino acids during hydrolysis where water is involved in the cleaving of peptide bonds.

Hydrolysis is a diagenic process, which causes the polypeptide fragments and free amino acids that were once part of the intact collagen structure to gain hydrogen and oxygen and contaminate the existing intact collagen (Pfeiffer and Varney, 2000).

Using the modified Bell *et al.*(2001) stable isotope pretreatment method, a sample of modern Pacific cod skeletal elements (n=31) has been used to establish baseline % collagen yield values (23%). The Mink Island samples were processed using the same modified Bell *et al.* (2001) stable isotope pretreatment method and compared to the modern % collagen yield values to assess preservation and contamination differences. If % collagen yields are lower than expected, the collagen may be degraded (van Klinken, 1999). If the % collagen yields are higher than expected, the sample may not have been completely demineralized during pretreatment (Bell *et al.*, 2001). Carbon content from the mineral portion of the bone may be contaminating the "collagen" which may not only affect yields, but may affect $\delta^{13}C$ values (Bell *et al,* .2001). By comparing % collagen yields of Mink Island specimens to their radiocarbon-dated levels, temporal variability in preservation may be assessed.

Collagen %C and %N by weight is a measure of the percentage of carbon and nitrogen by weight present in the pretreated bone collagen. As stated earlier %C by weight was derived from the amino acid sequence of Atlantic cod and should be between 41.04%-49.22% (Arnesen and Gildberg, 2006). The lower number (41.04%) represents completely hydrolyzed collagen (i.e., all amino acids are free after hydrolysis of all peptide bonds). The higher number (49.22%) represents pure unhydrolyzed type I collagen. Collagen %N by weight should be between 15.61% and 18.72% (Arnesen and Gildberg 2006) (Appendix F). The lower number (15.61%) represents completely hydrolyzed collagen and the higher number (18.72%) represents pure unhydrolyzed type I collagen. The closer the percentage is to the higher numbers, the better preserved the bone collagen sample. Samples that have lower %N and %C values than expected indicate the presence of inorganics. This is from either incomplete demineralization during the pretreatment process or contamination by exogenous carbon or nitrogen (Ambrose, 1993).

Although %C and %N by weight measurements are good indicators of bone collagen preservation/contamination levels, they are sometimes problematic. Collagen %C and %N values were derived from the amino acid sequence of Atlantic cod, but the Mink Island samples are Pacific cod. Although both species have similarly shaped bones, it is unknown how their

amino acid sequence may differ. Therefore, %C and %N values that are outside the acceptable ranges on the high side may reflect taxa-specific differences in amino acid sequence. This distinction is especially evident because many modern Pacific cod %C by weight values were higher than the acceptable reference range (they would not be contaminated by exogenous carbon or nitrogen from the burial matrix because they are modern samples). This situation was remedied by rejecting %C and %N by weight values that were substantially lower than the reference acceptable range while accepting slightly higher values.

The atomic C: N value was also derived from the amino acid sequence of Atlantic cod. It is calculated by dividing the %C by %N and multiplying the quotient by 1.167 (see Appendix F). The atomic C: N value of Atlantic cod is 3.07; the acceptable range is between 2.77 and 3.47. Those atomic C: N values that fall outside that range are rejected. High C: N values are the result of contamination by carbon-rich organics such as humic acids and lipids (van Klinken, 1999). Atomic C: N values are the easiest and most reliable way to assess stable isotope sample quality (Ambrose, 1993).

Results: BVD (Skeletal Element)

The results of $\delta^{15}N$ analysis and associated SD and CV values aggregated by skeletal element (and thus BVD values) are presented in Table 7.15. One-way ANOVA statistical analysis indicates that $\delta^{15}N$ values did not differ significantly ($F=1.976$; $df=5, 65$; $p=.094$) among the BVD categories. Therefore, BVD differences did not significantly affect $\delta^{15}N$ values (Appendix G.1). The SD and CV values of the dentary (e.g. 0.68 and 4.01, respectively) demonstrate that dentary $\delta^{15}N$ values were least variable; whereas the SD and CV values reveal that vomer $\delta^{15}N$ values were most variable (1.39 and 8.51, respectively). These results are expected because tests in the previous section confirmed that dentaries are best suited and vomers are one of the least suited skeletal elements for producing accurate stable isotope values.

Table 7.15. $\delta^{15}N$ assessment, SD, and CV values of Mink Island Pacific cod samples aggregated by BVD. BVD values were obtained from Smith (2008, Table 12, pp. 68).

$\delta^{15}N$ Assessment					
Pacific cod (*Gadus macrocephalus*)	**Number of Samples Analyzed**	**BVD g/cm^3**	**Mean δ15N**	**Standard Deviation**	**Coefficient of Variation**
Dentary	13	1.23	16.94	0.68	4.01
Quadrate	13	0.76	17.17	0.90	5.24
Vomer	14	0.85	16.34	1.39	8.51
Hyomandibular	6	0.47	16.09	0.93	5.78
Maxilla	12	0.92	16.87	0.72	4.27
Atlas Vertebra	13	0.76	17.11	0.94	5.49
All Elements	**71**	**N/A**	**16.81**	**1.00**	**5.95**

The results of $\delta^{13}C$ analysis, SD, and CV values aggregated by skeletal element (and thus BVD values) are presented in Table 7.16 and Appendix G.2. One-way ANOVA statistical analysis indicates that there is not a significant difference in $\delta^{13}C$ values ($F=1.87$; $df=5, 65$; $p=.112$) among BVD categories. As with the $\delta^{15}N$ values, the SD and CV values show that the dentaries are among the least variable (2 of 6), and the vomers are most variable. Again, these results are expected.

Table 7.16. $\delta^{13}C$ assessment, SD, and CV values of Mink Island Pacific cod samples aggregated by BVD. BVD values were obtained from Smith (2008), Table 12, pp. 68).

δ^{13C} Assessment					
Pacific cod (*Gadus macrocephalus*)	**Number of Samples Analyzed**	**BVD g/cm^3**	**Mean $\delta^{13}C$**	**Standard Deviation**	**Coefficient of Variation**
Dentary	13	1.23	-12.86	0.73	5.68
Quadrate	13	0.76	-12.64	0.80	6.33
Vomer	14	0.85	-13.02	1.20	9.22
Hyomandibular	6	0.47	-12.45	0.79	6.35
Maxilla	12	0.92	-12.27	0.66	5.38
Atlas Vertebra	13	0.76	-12.19	0.84	6.89
All Elements	**71**	**N/A**	**-12.60**	**0.90**	**7.14**

When the quality of the 72 Pacific cod samples are analyzed via %collagen yield, %C by weight, %N by weight, and atomic C: N values, it is possible to determine if the modified Bell *et al.*(2001) method is appropriate for use on archaeological fish bones. Additionally, by aggregating the assemblage by skeletal element, completeness %, and radiocarbon years BP, it is possible to determine if BVD, fragmentation, and the number of years the bones were buried affected preservation and contamination potential.

Analysis of the differences in % collagen yield among the skeletal elements (e.g. BVD) was completed using one-way ANOVA statistical analysis. The results revealed that % collagen yield differs significantly (F=3.08; *df*= 5, 65; p=.015) among the BVD categories. The vomer (M=7.00, 95% CI [5.04, 8.95]) and maxilla (M=7.35, 95% CI [5.55, 9.15]) possess smaller mean % collagen and SD values as compared to the remaining skeletal elements (Table 7.17). Therefore, maxillae and vomers are consistently more degraded than the other analyzed skeletal elements. The hyomandibulars possess the highest mean % collagen yield (M=15.50, 95% CI [8.65, 22.35]), however these samples are biased as they were only recovered from the most recent Mink Island context (Upper Midden). Based on the % collagen yield data, the atlas vertebrae (M=12.22, 95% CI [8.41, 16.03]) retained the most protein content, and therefore, are the best preserved.

One-way ANOVA analysis shows that differences in %C by weight values do not differ significantly among BVD categories (F=2.18, *df*=5, 66; p=.067). However, a p-value of .067 demonstrates that the samples are nearly correlated. As stated earlier the acceptable %C by weight values range between 41.04 and 49.22% (Arnesen and Gildberg, 2006) (See Appendix F). The lower number (41.04%) represents completely hydrolyzed collagen; therefore, higher values indicate better preservation. All of the skeletal elements tested fall within the acceptable ranges, however, the quadrate (M=45.90, 95% CI [39.57, 52.23]) and the hyomandibular (M=45.74, 95% CI [42.48, 49.00]) tend to be better preserved than the vomer (M=43.78, 95% CI [37.08, 50.48]) and the atlas vertebrae (M=43.74, 95% CI [40.42, 47.06]) (Table 7.17).

One-way ANOVA analysis reveals that differences in %N by weight values do not differ significantly among BVD categories (F=.528; *df*= 5, 65; p=.754). Values should range between

15.61 and 18.72% (Arnesen and Gildberg, 2006) (See Appendix F). The lower number (15.61%) represents completely hydrolyzed collagen and the higher number (18.72%) represents pure unhydrolyzed type I collagen. The vomers (M=14.67, 95% CI [12.94, 16.40]), maxillae (M=15.25, 95% CI [14.17, 16.70]), and atlas vertebrae (M=15.25, 95% CI [14.60, 15.91]) have mean %N by weight values that are lower than the acceptable range (Table 7.17). The remaining skeletal elements have individual samples that fall below the acceptable %N by weight range. The data were used to demonstrate that BVD differences did not affect the amount of nitrogen retained in the bone. Other factors such as fragmentation and the burial duration played a larger role in preservation. This phenomenon is discussed further in a later section.

One-way ANOVA statistical analysis was used to determine that mean atomic C: N values differ significantly (F=2.45; *df*=5, 65; p=.043) among the BVD categories (Table 7.17). The vomer (M=3.54, 95% CI [3.33, 3.74]) possesses a significantly higher mean atomic C: N value ($p<.05$) than every other skeletal element. As the acceptable range of atomic C: N values for Pacific cod skeletal elements is 2.77-3.44, the vomer falls outside of the acceptable range. The remaining skeletal elements lie within the acceptable range, and are therefore suitable for stable isotope analysis.

When all of the stable isotope quality control indicators are examined in concert, a robust picture emerges (Table 7.17). Vomers, on average, did not pass the quality control assessment. Some skeletal elements passed one indicator test, but failed another by a small margin, which makes determining whether to use a sample difficult. In such cases, the atomic C: N value should be used to determine if a sample is accepted or rejected. In the following sections, stable isotope ($\delta^{13}C$, $\delta^{15}N$) are presented by radiocarbon years BP and by completeness % to assess data quality.

Table 7.17. Mean stable isotope quality control indicator (% collagen yield, %C by weight, %N by weight, atomic C: N) and SD values of Mink Island Pacific cod samples aggregated by skeletal element (BVD).

Stable Isotope Quality Control Indicators					
Pacific cod Skeletal Element	**Number of Samples Analyzed**	**Mean Collagen Yield and S.D.**	**Mean %C by Weight and S.D.**	**Mean %N by Weight and S.D.**	**Mean Atomic C:N and S.D.**
Dentary	13	10.16 ± 6.05	44.18 ± 8.28	15.60 ± 3.32	3.33 ± 0.15
Maxilla	12	7.35 ± 2.83	44.19 ± 5.04	15.44 ± 1.99	3.35 ± 0.12
Vomer	14	6.99 ± 3.39	43.78 ± 6.70	14.67 ± 3.00	3.54 ± 0.35
Quadrate	14	10.80 ± 7.04	45.90 ± 6.33	15.95 ± 2.48	3.37 ± 0.12
Atlas Vertebra	13	12.22 ± 6.30	43.74 ± 3.32	15.25 ± 1.09	3.35 ± 0.09
Hyomandibular	6	15.50 ± 6.53	45.74 ± 3.26	16.20 ± 1.38	3.30 ± 0.07
All Elements	**72**	**10.01 ± 5.89**	**44.47 ± 5.86**	**15.44 ± 2.41**	**3.38 ± 0.20**

Results: Radiocarbon Years BP

The results of $\delta^{15}N$ analysis as aggregated by calibrated radiocarbon years BP are presented in Table 7.18. One-way ANOVA statistical analysis reveals that $\delta^{15}N$ values differ significantly among radiocarbon year BP categories ($F=7.74$; $df=9, 92$; $p=.000$). The modern samples have significantly lower $\delta^{15}N$ values ($p<.01$) than the Mink Island samples. SD and CV values are also low among the modern samples (Table 7.18). The highest $\delta^{15}N$ values were associated with the Lower Midden assemblages (5047 and 5340 cal. BP). However, the differences in $\delta^{15}N$ values among the Mink Island samples (Thule through Ocean Bay I assemblages) are not significantly different. The high degree of overlap in $\delta^{15}N$ and SD values among the samples indicates that something other than the number of years the skeletal elements were buried is also influencing $\delta^{15}N$ values (Appendix G.3).

The $\delta^{15}N$ values (Table 7.18) could be used to infer change over time in the trophic level at which the individual Pacific cod ate at (Fry, 1988). Additionally, the $\delta^{13}C$ values (Table 7.19) could be used to infer change over time in primary productivity (Fry, 1988). However, reconstructing ecosystem structure and function is outside of the scope of this dissertation research. Additionally, if one were to attempt to reconstruct ecosystem structure and function

using archaeological fish bones, they would need to select different samples for analysis. Because Pacific cod eat a differing trophic levels depending on their age, it is essential to be able to reconstruct the age structure from the recovered fish bone. Therefore, fork length would need to be determined using osteometric analysis (hyomandibulars and maxillas were not tested via linear regression (Orchard, 2003). Additionally, sample sizes associated with each aggregation unit (e.g. radiocarbon dated level) should be large enough (n=30) to provide statistically significant values.

Table 7.18. Mean $\delta^{15}N$, SD, and CV values of modern and Mink Island Pacific cod samples aggregated by calibrated radiocarbon years BP.

$\delta^{15}N$ Assessment					
Calibrated Radiocarbon Years BP (2 Sig.)	**Cultural Affiliation**	**Number of Samples Analyzed**	**δ15N**	**Standard Deviation**	**Coefficient of Variation**
0	Modern	31	15.26	0.57	3.74
<535	Thule	6	16.64	0.90	5.41
535	Thule	6	16.58	1.46	8.81
735	Thule	3	16.23	0.71	4.37
745	Thule	3	16.42	0.50	3.05
910	Thule/Norton/Kachemak	6	17.40	1.24	7.13
915	Thule/Norton/Kachemak	6	16.80	1.18	7.02
1510	Norton/Kachemak	3	16.43	1.64	9.98
5047	Ocean Bay II	25	16.90	0.83	4.91
5340	Ocean Bay I	13	16.88	1.02	6.04
All Periods	**All Traditions**	**102**	**16.34**	**1.14**	**6.98**

One-way ANOVA statistical analysis supports the interpretation that $\delta^{13}C$ values differ significantly among radiocarbon year BP categories ($F=5.33$; $df=9, 92$; $p=.000$) (Table 7.19). As with the $\delta^{15}N$ values, the modern $\delta^{13}C$ values are significantly different from the Mink Island samples ($p<.01$), but the differences among the Mink Island assemblages are not significant ($p\geq.05$) during any period except Ocean Bay I (5340 cal. BP). The Ocean Bay I assemblage $\delta^{13}C$ values (M=-13.18, 95% CI [-13.97, -12.38]) are significantly higher than those from 745 (M=-12.08, 95% CI [-13.85, -10.31]) through 5047 (M=-12.40, 95% CI [-12.70, -12.10]) cal. BP. The associated SD and CV values are also high among the Ocean Bay I assemblage (Table 7.19 and Appendix G.4).

Table 7.19. Mean $\delta^{13}C$, SD, and CV values of modern and Mink Island Pacific cod samples aggregated by calibrated radiocarbon years BP.

$\delta^{13}C$ Assessment					
Calibrated Radiocarbon Years BP (2 Sig.)	Cultural Affiliation	Number of Samples Analyzed	$\delta^{13}C$	Standard Deviation	Coefficient of Variation
0	*Modern*	31	-13.55	0.62	4.58
<535	Thule	6	-13.09	0.88	6.72
535	Thule	6	-12.85	0.60	4.67
735	Thule	3	-12.66	0.72	5.69
745	Thule	3	-12.08	0.71	5.88
910	Thule/Norton/Kachemak	6	-12.21	0.71	5.81
915	Thule/Norton/Kachemak	6	-12.25	0.62	5.06
1510	Norton/Kachemak	3	-12.13	0.51	4.20
5047	Ocean Bay II	25	-12.40	0.73	5.89
5340	Ocean Bay I	13	-13.18	1.31	9.94
All Periods	**All Traditions**	**102**	**-12.89**	**0.93**	**7.21**

Results of the stable isotope quality control assessment associated with the radiocarbon-dated levels are presented in Table 7.20. One-way ANOVA statistical analysis reveals that % collagen yield values differ significantly among radiocarbon year BP categories (F=39.11; *df*= 9, 92; p=.000). Tukey post-hoc comparisons indicate that % collagen yields among the modern samples (M=23.13, 95% CI [22.38, 23.88]) are significantly higher than the Mink Island samples, therefore, protein content was increasingly lost because of the combined effects of biostratinomic and diagenic agents. The mean % collagen yields from samples dating to 735 cal. BP (M=9.27, 95% CI [6.41, 12.12]) are significantly lower than all of the assemblages except for those associated with the following assemblages (1510, 5047, and 5340 cal. BP). Likewise, the samples dating to 5047 (M=6.88, 95% CI [6.09, 7.67]) and 5340 cal. BP (M=5.3, 95% CI [3.86, 6.74]) possess significantly lower mean % collagen yield values. The low % collagen yields are expected for the 5047 and the 5340 samples, because diagenic agents have had a longer period to leach protein from the bone. However, the low % collagen yield associated with the 735 cal. BP is unexpected. Low sample size may be responsible for this discrepancy. Other quality control assessments may be used to help interpret this low value.

One-way ANOVA statistical analysis was used to determine that % C by weight values differ significantly among radiocarbon year BP categories (F=5.37; *df*=9, 92; p=.000). The modern specimens possess a significantly higher mean %C by weight value (M=49.57, 95% CI

[48.64, 50.50]) than half of the Mink Island assemblages (e.g. <535, 910, 1510, 5047, and 5340 cal. BP) (Table 7.20). However, the mean %C by weight values associated with the remaining assemblages are not significantly different (p>.05). The modern %C value is 49.57, which is slightly higher than that worked out from the amino acid sequence for Atlantic cod (*Gadus morhua*) (41.04-49.22%). Because the modern samples were not affected by biostratinomic or diagenic agents, the increase in %C by weight values likely reflects the difference beteen Pacific and Atlantic cod. Additional research is needed to explore these differences. Among the Mink Island assemblages, The Ocean Bay I (5340 cal. BP) assemblage has a mean %C by weight value of 40.36 (M=40.36, 95% CI [36.56, 44.17]), which indicates that samples are completely hydrolyzed (e.g. all amino acids are free after hydrolysis of all peptide bonds) and thus, highly degraded. All of the other %C by weight values are within the acceptable range, which suggests that they will produce acceptable stable isotope values. Higher %C by weight values associated with the 915 cal. BP assemblage (M=49.96, 95% CI [42.69, 57.24]) indicate that these bones tend to be better preserved than bones from the remaining assemblages. The lower mean %C by weight values associated with the <535 (M=43.86, 95% CI [35.38, 52.33])and the 1510 (M=42.28, 95% CI [30.44, 54.12]) cal. BP assemblages may be the result of increased biostratinomic agent action. More samples would need to be tested to explore these differences further.

One-way ANOVA statistical analysis was also used to determine that %N by weight values differ significantly among radiocarbon year BP categories (F=7.83; *df*=9, 92; p=.000). The modern samples possess higher mean %N by weight values (M=18.10, 95% CI [17.77, 18.42]) than all of the Mink Island samples except those associated with the 535, 735, 745, and 915 cal. BP assemblages (Table 7.20). Among the Mink Island salmples, differences in %N by weight values among the assemblages are insignificant except for the 5340 cal. BP assemblage. The 5340 cal. BP (Ocean Bay I) assemblage (M=13.52, 95% CI [11.75, 15.28]) possess a significantly lower (p<.05) %N by weight value than all other assemblages except the Ocean Bay II (5047 cal. BP) (M=15.35, 95% CI [14.84, 15.86]) and the most recent Thule (<535 BP)(M=15.09, 95% CI [11.62, 18.55]) assemblages. Because the %N by weight values associated with the 5340, 5047, 1510, and <535 cal. BP assemblages fall ouside of the acceptable range (e.g. 15.61-18.72), these assemblages are highly depleted of nitrogen and thus, should be rejected. However, because

these values are the mean from the assemblage, those individual values that meet quality control may still be used for analysis.

The final quality control indicator used here to assess the stable isotope values is the atomic C: N value. One-way ANOVA was used to determine that atomic C: N values differ significantly among radiocarbon year BP categories ($F=5.92$; $df=9, 92$; $p=.000$). The modern samples (M=3.20, 95% CI [3.19, 3.20]) possess a significantly ($p<.05$) lower mean atomic C: N value than the following Mink Island samples <535, 535, 910, 5047, and 5340 cal. BP (Table 7.20). Differences among the remaining assemblages (735, 745, and 915 cal. BP) and the modern samples are not significant ($p\geq.05$). The atomic C: N value determined from the amino acid sequence of an Atlantic cod is 3.07 and the acceptable range is between 2.77 and 3.47. The modern samples possess a mean value of 3.2, and the Mink Island assemblage mean values range between 3.27 and 3.55. Those assemblages with the lowest values, therefore, are best preserved. The high mean atomic C: N value associated with the Ocean Bay I (5340 cal. BP) assemblage (M=3.55, 95% CI [3.32, 3.78]) falls outside the acceptable range, and therefore those samples should be rejected. However if individual specimens meet quality control standards, they may be used.

When combined, bone preservation and contamination, as assessed by stable isotope quality control indicators, differ significantly ($p<.01$) among radiocarbon year BP categories. Because the modern assemblages were not affected by biostratinomic or diagenic agents, the stable isotope quality control indicators confirm they are extremely well preserved and uncontaminated, while the preservation of the Mink Island fish bone assemblages vary over time. The Lower Midden Ocean Bay I assemblage (5340 cal. BP) was plagued by preservation and contamination problems, which led to most samples being rejected. The Ocean Bay II (5047 cal. BP) and the Thule (<535 BP) assemblages were also affected by preservation and contamination. The poor stable isotope quality of the bones associated with Ocean Bay II assemblage is likely because they were buried for a long period. However, the poor quality associated with the Thule (<535 BP) assemblage is not because of time, and is likely because of other factors. The Thule assemblage is close to the surface and was likely affected by trampling and contamination by the soil humus layer to a greater extent than other assemblages.

Table 7.20. Stable isotope quality control (% collagen yield, %C by weight, %N by weight, and atomic C: N) and SD values of modern and Mink Island samples aggregated by calibrated radiocarbon years BP

Stable Isototpe Quality Control Assessment						
Calibrated Radiocarbon Years BP (2 sig.)	Cultural Affiliation	Number of Samples Analyzed	Mean Collagen Yield and S.D.	Mean %C by Weight and S.D.	Mean %N by Weight and S.D.	Mean Atomic C:N and S.D.
0	Modern	31	23.13 ± 8.86	49.57 ± 2.53	18.10 ± 0.90	3.2 ± 0.02
<535	Thule	6	15.93 ± 7.27	43.86 ± 8.07	15.09 ± 3.30	3.42 ± 0.16
535	Thule	6	13.88 ± 4.84	47.62 ± 1.81	16.55 ± 1.02	3.36 ± 0.09
735	Thule	3	9.27 ± 1.15	46.47 ± 1.49	16.58 ± 1.02	3.27 ± 0.10
745	Thule	3	14.70 ± 8.84	47.47 ± 2.15	16.78 ± 1.16	3.30 ± 0.08
910	Thule/Norton/Kachemak	6	16.27 ± 5.96	45.47 ± 10.39	15.87 ± 3.71	3.35 ± 0.08
915	Thule/Norton/Kachemak	6	14.20 ± 6.78	49.96 ± 6.93	17.79 ± 2.34	3.28 ± 0.04
1510	Norton/Kachemak	3	11.97 ± 5.92	42.28 ± 4.77	14.95 ± 1.91	3.30 ± 0.06
5047	Ocean Bay II	26	6.88 ± 1.90	44.09 ± 3.02	15.35 ± 1.23	3.36 ± 0.11
5340	Ocean Bay I	13	5.30 ± 2.39	40.36 ± 6.30	13.52 ± 2.92	3.55 ± 0.37
All Periods	**All Traditions**	**103**	**13.99 ± 7.88**	**46.02 ± 5.59**	**16.25 ± 2.40**	**3.33 ± 0.19**

Results: Completeness Percentage

In this final section, one-way ANOVA statistical analysis is used to determine if $\delta^{13}C$ and $\delta^{15}N$ values and associated quality control indicators (e.g. % collagen yield, %C by weight, %N by weight, and atomic C: N values) differ significantly among completeness % categories. One-way ANOVA shows that $\delta^{15}N$ values do not differ significantly among completeness % categories ($F=.869$; $df= 9, 61$; $p=.557$). Mean $\delta^{15}N$ values range from 16.23 and 17.54 (Table 7.21), and SD and CV values are highly variable. The range of $\delta^{15}N$ values and SD values do not increase as completeness % values decrease. Additionally, there is a high degree of overlap among the completeness % values (Appendix G.5). Therefore, $\delta^{15}N$ stable isotope values were not affected by differential completeness/fragmentation rates.

Table 7.21. Mean $\delta^{15}N$, SD, and CV values of Mink Island Pacific cod samples aggregated by completeness %.

$\delta^{15}N$ Assessment				
Completeness Percentage	**Number of Samples Analyzed**	**Mean $\delta^{15}N$**	**Standard Deviation**	**Coefficient of Variation**
10	8	16.50	1.15	6.97
20	10	16.77	0.83	4.95
30	8	16.86	0.82	4.86
40	5	17.10	1.35	7.89
50	5	16.99	0.87	5.12
60	12	16.67	1.06	6.36
70	4	16.78	0.67	3.99
80	5	16.76	1.42	8.47
90	8	17.54	0.80	4.56
100	6	16.23	1.06	6.53
Total	**71**	**16.81**	**1.00**	**5.95**

One-way ANOVA demonstrates that $\delta^{13}C$ values do not differ significantly among completeness % categories (F=2.65; *df*= 9, 61; p=.012). This pattern differs from the $\delta^{15}N$ values (F=.87; *df*=9,61; p=.557). The Pacific cod samples that were 10% complete possess a significatly lower mean $\delta^{13}C$ value (-13.71) compared to skeletal elements that were more complete (-12.02 through -12.89) (Table 7.22 and Appendix G.6). The associated SD and CV values are also higher with the 10% complete samples as compared to the more complete bones (20-100%). This pattern suggests that preservation and contamination (e.g. increased carbon) is affecting $\delta^{13}C$ values. Therefore, skeletal elements that are 10% complete were generally unsuitable for stable isotope analysis. Tukey post-hoc comparisons indicate that the remaining skeletal elements (20-100%) do not possess significantly different (p>.05) $\delta^{13}C$ values, and those values were generally not affected by preservation and contamination. The 100% complete samples also possess a high $\delta^{13}C$ value (-12.89), and carbon contamination may be affecting the samples. This phenomenon is explored using the quality control indicators.

Table 7.22. Mean $\delta^{13}C$, SD, and CV values of Mink Island Pacific cod samples aggregated by completeness %.

$\delta^{13}C$ Assessment				
Completeness Percentage	**Number of Samples Analyzed**	**Mean $\delta^{13}C$**	**Standard Deviation**	**Coefficient of Variation**
10	8	-13.71	1.28	9.34
20	10	-12.64	0.87	6.88
30	8	-12.66	0.52	4.11
40	5	-12.63	0.59	4.67
50	5	-12.06	0.81	6.72
60	12	-12.29	0.66	5.37
70	4	-12.59	0.70	5.56
80	5	-12.45	0.77	6.18
90	8	-12.02	0.73	6.07
100	6	-12.89	0.89	6.90
Total	**71**	**-12.60**	**0.90**	**7.14**

Stable isotope quality control indicators and SD values are presented in Table 7.23. One-way ANOVA statistical analysis was used to determine that % collagen yield values differ significantly among completeness % categories (F=10.94; *df*=9 61; p<=.000). In general, mean % collagen yield increased as the completeness % increased. However, among the eight skeletal elements that were 90% complete, the mean % collagen value is lower (11.76, 95% CI [8.37, 15.15]). As the mean % collagen yield derived from the 31 moden Pacific cod samples is 23%, it is clear that bone collagen was lost because of biostratinomic and diagenic agent action. Because % collagen yield may be affected by stable isotope pretretment methods, the other quality control indicators will be used to determine if the decreased % collagen yield among the 90% complete samples reflects a preservation or a pretreatment issue. The collagen yield values associated with the 20% (M=5.89, 95% CI [4.98 6.81]) and 10% (M=4.62, 95% CI [3.09, 6.16]) complete assemblages are low, and preservation conditions may affect stable isotope values. However, by selecting skeletal elements that are at least 30% complete (M=6.31, 95% CI [5.74, 6.88]), problems with low % collagen yield may be avoided.

One-way ANOVA statistical analyis was used to reveal that %C by weight values differ significantly among completeness % categories (F=2.94; *df*=9, 61; p=.006). Tukey post-hoc

comparisons demonstrate that the %C by weight value of the skeletal elements that are 10% complete (M=36.80, 95% CI [31.96, 41.63]) is significantly lower (p<.01) than those from all other completeness percentages (Table 7.23). The mean value is (36.80) is lower than the acceptable range (41.04-49.22) (Table 7.24), therefore, the 10% complete samples are highly degraded and should not be used for stable isotope analysis. All other %C by weight values fall within the acceptable range, and therefore may be used for stable isotope analysis. Additionally, the high value associated with the 90% complete assemblage (M=48.22, 95% CI [42.15, 54.28]) demonstratess that preservation conditions likely did not affect preservation and the low % collagen yield value is likely as the result of the pretreatment method. Some of the collagen may have been lost during the final rinsing stage using the Bell *et al.*(2001) method. This problem may be avoided in the future by using pipettes to remove liquids from the sample vials rather than pouring liquids.

One-way ANOVA statistical analyis was used to determine that %N by weight values differ significantly among completeness % categories (F=3.96; *df*=9, 61; p=.001). Again, the 10% complete samples possess significantly (p<.01) lower mean %N by weight values (M=11.79, 95% CI [9.61, 13.97]) than any of the other samples that were more complete (20-100%) (Table 7.23). As the acceptable range of %N by weight values is between 15.61 and 18.72, the 10% complete value (11.79) is not acceptable (Table 7.24). Therefore, the 10% complete samples should not be used for stable isotope analysis. Mean %N by weight ranges are also below the acceptable range among the 20% (M=15.30, 95% CI [14.51, 16.09]) and 100% (M=14.48, 95% CI [9.87, 19.08]) complete samples. While the low values may be expected among the 20% complete specimens, the low values associated with the 100% complete specimens can not be explained through fragmentation related preservation conditions. The low mean %N by weight value associated with the 100% complete specimens is related to incomplete demineralization. Therefore, the most complete samples needed to be treated with the HCl solution (0.5 M) for additional time to completely demineralize the samples. However, because the 90% samples fall within the acceptable range, only the 100% complete samples need additional time. When the outer cortical bone is intact, it protects the inside of the bone from diagenic agents. Since the HCl mimics the effects of diagenic agents, cortical bone also protected the inside of the bone from HCl action. If even a small portion of the cortical bone has lost its integrity (e.g. 90%),

diagenic agents and HCl is able to gain access to the interior portion of the bone and degrade/dissolve it from the inside-out.

One-way ANOVA statistical analyis was also used to determine that atomic C: N values differ significantly among completeness % categories (F=3.82; *df*= 9, 61; p=.001). The 10% complete samples possess significantly higher atomic C: N values (M=3.70, 95% CI [3.35, 4.05]) compared to the other completeness % assemblages (Table 7.23). The 10% complete samples are contaminated by carbon-rich organics such as humins. As the 10% complete specimens fall outside the acceptable range (e.g. 2.77-3.47), they are not suitiable for stable isotope analysis. All of the other completeness % contain mean atomic C: N values that are within the acceptable range. However, the higher value associated with the 100% complete assemblage (M=3.42, 95% CI [3.27, 3.57]) is on the high end of acceptable and likely reflects incomplete demineralization. This pattern of incomplete demineralization may not have been visible if multiple indicators of stable isotope quality were not used. As the atomic C: N value determined from the amino acid sequence is 3.07 (Arnesen and Gildberg, 2006) (Table 7.24), those assemblages with the lowest (3.31) mean atomic C: N values indicate better preservation. Surprisingly, the best values were derived from assemblages that were between 50 and 70 % complete.

In sum, the combined stable isotope quality control indicator values reveal a couple of patterns within the completeness % assemblages. Pacific cod samples that are 10% complete are not suitable for stable isotope analysis as they are affected by contamination and preservation problems. Additionally, the indicator data shows that the 100% complete samples require additional time within the HCl wash to remove all of the mineral component of the bone. Although the values do fall within the acceptable range, they should be used with caution as carbon from the mineral portion of the bone is undoubtedly affecting $\delta^{13}C$ values. The skeletal elements that range from 30 to 90 % complete, typically produce stable isotope values that meet quality control standards. Some but not all of the 20% complete samples met quality control standards, therefore these samples must be evaluated individually.

Table 7.23. Stable isotope quality control indicators (%collagen yield, %C by weight, %N by weight, and atomic C: N) of Mink Island Pacific cod samples aggregated by completeness %.

Stable Isotope Quality Control Indicators					
Completeness Percentage	Number of Samples Analyzed	Mean Collagen Yield and S.D.	Mean %C by Weight and S.D.	Mean %N by Weight and S.D.	Mean Atomic C:N and S.D.
10	8	4.63 ± 1.84	36.80 ± 5.78	11.79 ± 2.61	3.70 ± 0.42
20	10	5.89 ± 1.28	44.12 ± 2.39	15.30 ± 1.11	3.38 ± 0.13
30	8	6.31 ± 0.68	46.11 ± 2.83	16.12 ± 1.16	3.34 ± 0.13
40	5	8.90 ± 1.76	47.27 ± 1.02	16.61 ± 0.30	3.32 ± 0.07
50	5	8.62 ± 1.19	44.82 ± 2.97	15.79 ± 1.16	3.31 ± 0.05
60	12	9.56 ± 3.30	44.54 ± 3.54	15.73 ± 1.42	3.31 ± 0.06
70	4	15.75 ± 8.35	47.65 ± 1.82	16.83 ± 0.91	3.31 ± 0.06
80	5	18.90 ± 6.27	45.77 ± 4.81	16.03 ± 1.62	3.33 ± 0.10
90	8	11.76 ± 4.06	48.22 ± 7.25	16.87 ± 2.72	3.34 ± 0.10
100	6	18.35 ± 7.31	42.14 ± 11.71	14.48 ± 4.39	3.42 ± 0.14
Total	**71**	**10.01 ± 5.89**	**44.47 ± 5.86**	**15.44 ± 2.41**	**3.38 ± 0.20**

Table 7.24. Bone collagen quality control indicators (% collagen yield, %C by weight, %N by weight, and atomic C: N) of typical modern mammal and Atlantic cod bone.

Bone Collagen Quality Indicators Mammals Vs. Fish			
Quality Indicator	Typical modern mammal bone	Typical Atlantic Cod Bone	Potential Problems
Collagen Yield	20-30%[a]	28-18%[d]	Low Yield: Collagen degraded High Yield: Sample not demineralized
%C by Weight	42.20-50.51%[b]	41.04-49.22%[d]	Low %C: Presence of inorganics
%N by Weight	15.35-18.37%[b]	15.61-18.72%[d]	Low %N: Presence of inorganics
Atomic C: N	3.20[c]	3.07[d]	High C: N value: Carbon contamination (e.g. organics, sample not demineralized).

[a]Kennedy (1988), [b]Lower value is from Ambrose (1993), upper value from Kennedy (1988). [c]Ambrose (1993); [d]From calculations in Appendix F (derived from the amino acid sequence presented by Arnesen and Gildberg, 2006).

Conclusions: Suitability of the Modified Bell et al. (2001) Method

Based on the quality control indicator data, the Bell *et al.* (2001) pretreatment method as modified is suitable for use with archaeological fish bones. The modified Bell *et al.*(2001) pretreatment method works well with ancient fish bones because it uses a weak acid concentration (0.5 M HCl) for shorter periods (60 minutes), it does not use heat, and it uses hexane: Isopropanol (less harsh) to extract lipids. The primary problem with the method is because it uses powdered bone, which is difficult to handle because it requires centrifuging, and some sample is inevitably lost when pouring off liquids. Additionally, contamination by particulate organic matter and humins that were not removed by gelatinization may be a factor. The problem associated with sample loss may be overcome by increasing the length of time samples are centrifuged (from 15 to 30 seconds) and by using a pipette to remove liquids rather than pouring samples. Moreover, contamination may be avoided by collecting samples from the top portion of the sample vial, as visible contaminants tend to be concentrated on the bottom of the sample vial.

The problem associated with incomplete demineralization of those skeletal elements that are 100% complete may be overcome by increasing the time the samples were associated with the HCl wash from 60 to 70 minutes. The additional ten minutes should provide enough time to demineralize samples. As the quality control indicators are within borderline/acceptable ranges, the HCl wash time will only need to be increased a small amount.

The overall quality of stable isotope ($\delta^{13}C$, $\delta^{15}N$) values will increase by using the quality control indicators that have been adjusted for use with fish bone assemblages. Quality indicators that were derived from the amino acid sequence of fish are better for assessing the quality of stable isotope values than those that were derived from the amino acid sequence for mammals. Fish bones possess higher percentages of serine and glycine, and lower percentages of hydroxyproline and proline as compared to mammal bones (Szpak, 2011). Therefore, fish bones have differing baseline collagen yield, %C by weight, %N by weight, and atomic C: N values. Without adjusting for these class-level differences, stable isotope values may be skewed by preservation and contamination biases

Discussion

The assessment of cooking/burning stage revealed that Petchey and Higham's (2000) Munsell (1954) color-based method is not suitable for assessing the temperature to which an archaeological fish bone was heated. Absorption of diagenic contaminants from the burial environment (e.g. humic acid, fulvic acid, and humins) affect color, and therefore, must be removed before the cooking/burning stage may be assessed. However, because stable isotope pretreatment methods cannot remove all contaminants (e.g. humins) without applying heat, this method is not suitable for assessing cooking/burning stages. Subjecting the samples to additional heat while attempting to assess the temperature to which a bone was heated is counterproductive. Therefore, other methods (e.g. SEM and X-Ray diffraction) are better suited to assess cooking/burning stage.

The preservation assessment (e.g. physical appearance, BB%N, BB%C, and % collagen yield) revealed that preservation potential is not augmented by increased BVD. The densest bones were not the best-preserved bones. With the exception of the physical appearance class, preservation potential differs significantly among completeness % categories. As fragmentation increases, preservation decreases. As long as the outer cortical bone retains its integrity, preservation is good. If the cortical bone is breached, preservation decreases as ions are leached from the bone. With the exception of physical appearance class, preservation potential also differs significantly among radiocarbon year BP categories. Modern skeletal elements are significantly better preserved than the Mink Island skeletal elements. Skeletal elements became leached quickly after being buried. The rate of leaching decreased as the skeletal elements achieved chemical equilibrium with the burial environment. As the combined effects of compaction and leaching affected fish bones associated with the Ocean Bay I assemblage (5340 cal. BP) more than other assemblages, they possess decreased preservation potential.

Preservation is best assessed using BB%N, BB%C, and % collagen yield. Physical appearance class assessments did not accurately predict overall preservation, and therefore should not be used. Because % collagen yield may be completed through the stable isotope pretreatment process, is easy to calculate, and does not require additional analysis, it is the preferred method and should be calculated before sending samples for $\delta^{13}C$, and $\delta^{15}N$ analysis

The carbon contamination assessment (e.g. actual versus expected BB%C values) revealed that carbon contamination differs significantly (negatively) among BVD categories. The most dense bones tend to be the most contaminated bones and the least dense bones tend to be the least contaminated. Therefore, increased BVD values are not associated with decreased contamination values. There are, however, significant differences in carbon contamination among completeness % categories. As skeletal elements become more fragmented, contamination increases. As long as the outer cortical bone retains its integrity, contamination remains low, however if the cortical bone is breached, contaminates gain access to the interior portion of the bone. There are also significant differences in carbon contamination among radiocarbon years BP categories. Skeletal elements at the bottom and the top of the shell midden tend to be more contaminated than those located within the middle of the context. Those skeletal elements at the bottom of the shell midden tend to be more affected by soil compaction (fragmentation) and leaching. As rainwater percolates through the shell midden, water-soluble carbon contaminants travel through the matrix until they settle at the base of the midden. As the shell midden matrix dries out, the contaminants are absorbed into the open pore spaces. Those skeletal elements near the surface of the shell midden also tend to be more affected by trampling and contamination. These skeletal elements at the top of the shell midden are adjacent to the soil humus layer, which causes them to degrade and become contaminated faster.

When combined, the preservation and contamination assessments reveal that the degree to which a skeletal element is fragmented is related to the burial duration. Therefore, the high SD values associated with each of the preservation and contamination indicator values indicates that both factors must be considered when choosing fish bone samples for stable isotope values. Because the reconstruction of ecosystem structure and function typically requires testing of fish bones from multiple radiocarbon-dated levels that span the length of occupation at an archaeological site, it is imperative that only the most complete skeletal elements be chosen for analysis. These skeletal elements should be free of visible contaminants, be un-burned, have a smooth outer cortical bone layer, and have a known relationship between individual skeletal element measurements and fork length. Dentaries have the highest potential to meet these qualifications. As long as these qualifications are met,

stable isotope values should reflect changes in ecosystem structure and function rather than differences in contamination and preservation.

The assessment of the Bell *et al.* (2001) stable isotope pretreatment method, as modified, revealed that it is suitable for use with archaeological Pacific cod bones. However, among modern samples and complete skeletal elements from Mink Island, the modified Bell *et al.* (2001) method must be adjusted. The samples should be retained in the 0.5M HCl wash for an additional 10 minutes to insure complete demineralization. These samples possess an intact outer cortical bone layer that requires additional time for the HCl to breach. Skeletal elements that are fragmentary (e.g. 90-10% complete) have compromised cortical bone layers, and therefore the acid is able to enter the interior portion of the bone and demineralization begins on inside surfaces. Therefore, in these cases, the modified Bell *et al.* (2001) pretreatment does not need adjustment.

Regardless of the specific pretreatment methods used to prepare fish bones for stable isotope analysis, it is essential to assess the quality (e.g. %C by weight, %N by weight, atomic C: N) of the stable isotope ($\delta^{13}C$ and $\delta^{15}N$) values. The raw data that accompanies the stable isotope values (e.g. %C by weight and %N by weight) are used to determine atomic C: N [(%C/%N) x 1.167], which is the best indicator of preservation and contamination. Because fish bones have a different structural and chemical composition compared to mammal bones, the quality control indicators must be adjusted accordingly. Fish bones possess lower %C by weight and higher %N by weight values than mammal bones. Therefore, atomic C: N values are also lower among fish bones. Without adjusting for the structural and chemical differences between mammals and fishes, stable isotope values may be skewed by using improper quality control indicators.

The taphonomic analysis conducted in this and the previous chapter are used in Chapter 8 to refine interpretations of fish bone abundance. The preservation data, which revealed the taxa and skeletal elements that are most likely to be underrepresented within the Mink Island assemblages, is consulted when interpreting the results. Therefore, the data presented in Chapter 8 is less biased and may be used to explore the interactions among humans and fishes at Mink Island.

Chapter 8. Interactions among Humans and Fishes at Mink Island

Introduction

Interactions among humans and fishes are explored in this chapter using a four-stage resource depression and intensification model derived from optimal foraging theory. The chapter begins by introducing optimal foraging theory, which includes descriptions of several associated mathematical models (e.g. prey choice/diet breadth and patch choice/marginal value theorem). The benefits and constraints of using optimal foraging theory to explain temporal changes in the foraging behaviors of prehistoric hunter-gatherer groups are also described. Afterwards, the four-stage resource depression and intensification model is presented. The model employed here has been modified from those developed by Fitzhugh (1996), Kopperl (2003), and Partlow (2000) for use with fish bone assemblages. Model stage descriptions include radiocarbon age-ranges, cultural phases, mobility patterns, site distributions, habitation types, foraging strategies, faunal assemblages, and artifact toolkits. The prey choice/diet breadth and patch choice/marginal value theorem models are also incorporated into the model. Accounts of the available fish taxa and associated marine and riverine resource patches that were available to the Mink Island occupants are also provided. Descriptions of archaeological applications of the prey/diet breadth choice and patch choice/marginal value theorem model are included.

Research questions and hypotheses are presented in the following section, and are aimed at identifying the ways that foraging behaviors changed over time at Mink Island. The first hypothesis uses the prey choice/diet breadth model to explore how taxonomic abundance (e.g. %NISP and %MNI) and diversity (NTAXA) changed over time in relation to the four stages of the resource depression and intensification model. The second hypothesis uses changing age structure data derived via linear regression analysis of Pacific cod quadrates (patch choice/marginal value theorem) to ascertain if evidence of resource depression(s) is/are present at Mink Island. The third hypothesis uses taxonomic proportions (Salmon Index), evenness (Shannon Index of Evenness), and storage evidence (cranial versus post-cranial skeletal elements) data to explore evidence of resource intensification of salmon. This hypothesis

employs both prey choice/diet breadth and patch choice/marginal value theorem models to explain changes in foraging behaviors. Lastly, the Mink Island fish bone data is compared to fish bone data from other sites within the region (e.g. Rice Ridge and Settlement Point) to determine if changing foraging behaviors at Mink Island fit the regional pattern.

Theoretical Framework: Optimal Foraging Theory

Optimal foraging theory (a subset of evolutionary ecology) has been used to explain why cultural groups express differing foraging behaviors (Bettinger, 1991; Boone and Smith, 1997; Broughton and O'Connell, 1999). Optimal foraging theory is used here to explore why hunter-gatherer groups within the Shelikof Strait coast region employed differing resource depression and intensification strategies over time. By comparing shifts in prey abundances, climatic conditions, and procurement locations/methods with shifts in resource depression and intensification strategies, it is possible to determine causal variables (Grayson, 2001). Once the causal variables are known, it becomes possible to predict foraging behaviors (Bettinger, 1991).

Biologists first developed optimal foraging theory during the second half of the twentieth century in an attempt to explain how variability in foraging-related traits of living organisms affected reproductive fitness (Stephens and Krebs, 1986). Models derived from optimal foraging theory share a common trait in that they all assume that foraging behaviors have been molded by natural selection in attempts to maximize reproductive fitness (Smith and Winterhalder, 1992; Stephens and Krebs, 1986). In doing so, optimal foraging models provide a means in which researchers may predict which prey items will be pursued in relation to their availability (e.g. location and timing) across the landscape (Kaplan and Hill, 1992).

The basic models of foraging theory in anthropology often employ ethnographic data, which uses subsistence practices of modern hunter-gatherer communities, to predict foraging behavior. Ethnographic data have been shown to be effective in predicting and explaining the foraging behavior of prehistoric hunter-gatherers (e.g. Hawkes *et al.*, 1982; Hill *et al.*, 1987; Hames and Vickers, 1982). Ethnographic research is beneficial for model building because real-time observation of energy spent, risks taken, and benefits gained helps the researcher to make informed assumptions about prehistoric strategies. However, because modern foraging

strategies are not always directly comparable to prehistoric foraging strategies and those strategies employed by modern and prehistoric individuals are not always optimal; ethnographic data must be used with caution (Smith and Winterhalder, 1992). In fact, there are several instances where foraging behavior by hunter-gatherer groups does not fit the optimal foraging model, which uses maximum net energetic returns as the largest factor in deciding strategies (e.g. Hurtado *et al.*, 1985; Kaplan and Hill, 1992; Kelly, 1995). In such instances, the reproductive costs of risky subsistence pursuits and costly signaling may be driving foraging behavior (Kelly, 1995). For example, an individual may participate in risky behavior that is suboptimal in relation to net energetic returns; however, they proceed because it affords them increased status (e.g. Fitzhugh, 1996).

The Prey Choice/Diet Breadth Model

The prey choice model, also known as diet breadth, is one of the most general models of optimal foraging theory. This model predicts which food items foragers will pursue and which items they will neglect (Bettinger, 1991; Smith, 1991; Kaplan and Hill, 1992). The prey choice model contains three components (decision, currency, and constraint) (Bettinger, 1991). Decision refers to if an individual should pursue a specific prey item when it is encountered or if they should move on and search for other prey items. Currency determines which factors are to be minimized, maximized, or maintained (i.e. minimizing risk while maximizing net energetic returns). Constraints comprise the other factors that are incorporated in the model that influence decisions (e.g. knowledge of prey distribution, abundance, energetic return rates, etc.) (Bettinger, 1991). Incorporated within the prey choice model is the assumption that prey items are randomly encountered, homogeneously distributed, and pursued in sequential order (highest ranked to lowest rank) (Charnov, 1976; Stephens and Krebs, 1986).

The mathematical expression of the prey choice model is: $R_{max} = (E/T)_{max}$. Where R_{max} is the maximum rate of energy acquired from foraging; E is the total net energy return from a certain diet breadth, which includes the energy value derived from prey types and the energy costs of pursuing, processing, and consuming of prey types; and T is the total foraging time spent using those resources. This model solves for a diet breadth that offers the maximum

amount of energetic returns. Prey items will be added to the diet in order from most profitable to least profitable until R_{max} is achieved. Prey items with the highest net energetic returns (highest ranking) will always be exploited when encountered. Prey items with lower net energetic returns (lower ranking) will be exploited until their addition into the diet lowers the overall energy procurement rate (Bettinger, 1991). The ranking of prey items not only considers the energetic food value of the item, it also incorporates the energetic costs of procuring the prey item (Bettinger, 1991; Stephens and Krebs, 1986; Winterhalder, 1981). The development of mass harvesting technologies allows small-bodied prey to obtain a higher rank (e.g. salmon). The net energetic return of these mass-harvested prey items is increased because the technological innovations (e.g. weirs and nets) allow large numbers of prey items to be harvested (Madsen *et al.*, 1998). Another related technological innovation is the advent of processing, preserving, and storing techniques that prevent spoiling of the mass-harvested salmon resources (Schalk, 1977).

The supposition that prey types are evenly distributed across the landscape and that foragers encountered them proportionally depending on their overall abundance with the area has been referred to by Stephens and Krebs (1986) as the fine-grained search assumption. However, because resources are often unevenly distributed (patchy) across the environment, the prey choice model may not be comprehensive enough to explain foraging behavior. Additionally, the prey choice model does not incorporate the fact that when a forager utilizes a particular resource patch for some length of time, the encounter rates of specific prey items will likely be reduced. Reduction in encounter rates may reflect decreased abundance of prey items, behavior adjustments by the prey items to avoid capture, and changes in the prey habitat that have nothing to do with human causes (Bettinger, 1991). To overcome some of the limitations associated with uneven distribution of prey items, the prey choice model may be used in concert with the patch choice model (Kopperl, 2003).

The Patch Choice/Marginal Value Theorem Model

The patch choice model compliments the prey choice model in that it incorporates a similar equation and contains the same constraining assumptions (MacArthur and Pianka, 1966). However, whereas the prey choice model is concerned with *what* prey items were pursued, the patch choice model is concerned with *where* the prey items were pursued (Stephens and Krebs, 1986). With the patch choice model, resource patches are ranked based on net energetic returns. Foragers will exploit the highest ranked resource patches preferentially and then add lower ranking patches to their foraging round. When a resource patch's net energetic returns are low enough, a forager may choose to leave that patch unexploited as it may decrease overall foraging efficiency (Stephens and Krebs, 1986).

As seen with the prey choice model, the patch choice model does not account for the ways foragers affect encounter rates within a resource patch. To overcome this problem, the marginal value theorem has been added to the patch choice model. The marginal value theorem allows the effects of resource depression to be considered when predicting which resource patches will be exploited by foragers (Charnov, 1976). For instance, when relatively slow-reproducing prey is continually pursued within a resource patch, net energetic returns may decrease over time (Charnov, 1976; Kaplan and Hill, 1992; Stephens and Krebs, 1986). The length of time in which a forager will spend in a particular resource patch will depend on the expected search effort required to locate another resource patch within the forager's patch breadth. The marginal value theorem predicts that foragers will remain within a depleted resource patch at the expense of foraging efficiency if the costs to moving to a new resource patch are high enough (Charnov, 1976). However, in locations with many diverse and productive habitats, a forager would likely relocate to a new resource patch as soon as there was a reduction in foraging efficiency (Stephens and Krebs, 1986). If a particular resource patch containing high-ranking prey items was left unexploited for some time, it may rebound and be available for exploitation once again (Stephens and Krebs, 1986).

Archaeological Application of Optimal Foraging Models

A central goal of resource depression models is to measure the foraging efficiency of hunter-gatherers within and between resource patches. An additional goal is to determine if decreased harvesting efficiency occurred as a direct result of harvesting pressure. The application of these optimal foraging models to archaeological data is an arduous task, as it requires testing hypotheses that cover a large time-span. Archaeological applications must also estimate diet breadth, processing, transport, and consumption costs, in addition to determining if these patterns change over time (Grayson and Cannon, 1999).

Diet breadth is a common measure of the foraging efficiency associated with a resource patch. The prey choice model assumes that as the number of prey types exploited by foragers increase, resource intensification occurs and foraging efficiency declines. Therefore, intensification may be measured within an archaeological faunal assemblage by measuring taxonomic distribution. However, this approach is problematic as a narrow diet is not necessarily more efficient than a broad one. To overcome this problem, it is essential to incorporate the relative abundance of high-ranking taxa.

An additional problem affecting archaeological applications is that it is typically impossible to determine the relative abundance of specific taxa that lived in a resource patch hundreds or thousands of years ago. One way to overcome this problem is to measure changes in foraging efficiency by examining changes in the proportions of taxa (e.g. %NISP, %MNI, etc.) rather than relying on absolute numbers (Kopperl, 2003). Changes in foraging efficiency may not be visible simply by tracking changes in diet breadth (i.e. number of prey types used). For example, two fish bone assemblages may be comprised of the same four taxa (e.g. Pacific cod, salmon, Irish lords, and halibut) but in different proportions (e.g. salmon compose 24% of the first assemblage but 78% of the second assemblage). If diet breadth was the sole consideration, both assemblages would display a similar pattern (e.g. diet breadth = 4 fish taxa). However, when the relative abundance is also considered, %NISP values indicate a dependence on salmon in assemblage 2. Therefore, %NISP values are an essential factor in estimating foraging efficiency of prehistoric groups.

Resource depression models were also developed to overcome the problems associated with diet breadth by focusing on temporal changes in age structures of a taxon (e.g. Pacific cod). As age structures are strongly correlated with body size, and overall body size may be inferred from zooarchaeological remains (e.g. Cannon, 2001; Orchard, 2003), age structures may be used to assess foraging efficiency. Therefore, zooarchaeological assemblages that are dominated by larger-bodied Pacific cod individuals (e.g. larger fork lengths) are indicative of increased foraging efficiency. However, it is also necessary to control for other factors (e.g. climate change and capture locations) because they may also affect age structures.

Increases in fork lengths (e.g. increased foraging efficiency) of Pacific cod and other marine fishes may also be explained by temperature changes of the North Pacific Ocean. Anderson and Piatt (1999) conducted a study where trends in catch biomass were analyzed between 1972 and 1997, which corresponded with a climate shift from a cold- to a warm-regime. They determined that Pacific cod abundance increased during the warming period (Anderson and Piatt, 1999). Therefore, if this relatively recent shift in Pacific cod abundance related to a changing climate regime is used as a proxy for prehistoric shifts in abundance, one may expect to see an increase in Pacific cod abundance during warm intervals (e.g. Hypsithermal and Medieval Warm Period) and a decrease in abundance during cold intervals (e.g. Neoglacial and Little Ice Age). Because an abundant Pacific cod population is less likely to be affected by harvesting pressure (Anderson and Piatt, 1999; Kopperl, 2003), fork lengths should be increased during warm intervals and decreased during cold intervals.

Additionally, because fishes tend to inhabit different locations depending on their age class (Rogers *et al.*, 1986), increases in fork lengths of Pacific cod and other marine fishes may be explained by use of differing capture locations. For instance, juvenile Pacific cod typically inhabit near-shore locations, whereas adults typically inhabit the bottoms of deep bays, straits, and the continental shelf (Rogers *et al.*, 1986). Therefore, Pacific cod that were captured from shore (e.g. beaches, etc.) would be expected to be smaller (e.g. reduced fork lengths) than Pacific cod that were captured using a boat (e.g. near shore marine patches). For instance, if an assemblage is comprised of juvenile Pacific cod (e.g. reduced fork lengths) coupled with small taxa that inhabit nearshore waters (e.g. sculpins, greenlings, saffron cod, etc.), it may indicate that the fishes were captured from shore. Conversely, if an assemblage is composed primarily

of adult Pacific cod (e.g. increased fork lengths), it may indicate that the fishes were captured from a boat in near-shore or off-shore marine patches.

Resource Depression, Intensification, and Cultural Complexity

Several prehistoric hunter-gatherer groups living on the Pacific coast of North America displayed increased sedentism, densely populated settlements, social ranking, complex labor organization, elaborate ceremonialism, warfare, and slavery that distinguished them from their interior neighbors (Arnold, 1996). These characteristics relied heavily on technological innovations that allowed for the mass harvesting and storage of food, especially salmon (Arnold, 1996). The development of cultural complexity, on the Northwest Coast and has been central to anthropological inquiry for over a century (Arnold, 1996; Fitzhugh, 1996).

Although several causal factors are proposed to explain why cultural complexity developed among hunter-gatherers (e.g. sedentism, population pressure, labor organization, and food storage) (Arnold, 1993; Cohen, 1981; Keeley, 1988; Rosenberg, 1998; Schalk, 1977; Testart, 1982), cultural complexity likely emerged because of a combination of these variables (Fitzhugh, 2003). The most successful models, however, incorporate the effects of resource depression and intensification on sea mammal and salmon populations to explain cultural complexity (e.g. Ames, 1981; Arnold, 1992; Kopperl, 2003; Matson and Coupland, 1995; Partlow, 2000).

Before describing the roles that resource depression and intensity played in the emergence of cultural complexity, it is essential to possess a clear understanding of the terms. Resource depression occurs when there is a decrease in capture rates and sizes of specific prey in response to the increased predation pressure (Charnov *et al.*, 1976; Stephens and Krebs, 1986). Resource intensification occurs when there is an increase in the energy devoted by a group of individuals to harvest of a food source to obtain more of that resource (Beaton, 1991; Boserup, 1965). Although many cultural complexity models suggest that resource depression and intensification played some role in the development of cultural complexity, relatively few have attempted to demonstrate that intensification occurred (Kopperl, 2003). Even fewer have attempted to identify the possible causes of resource depression and intensification. Therefore,

following some of the methods established by Kopperl (2003), several hypotheses are tested to identify changes in resource depression and intensification at Mink Island.

Cultural complexity models often focus on intensification of salmon harvesting for an important reason. Salmon populations tend to be a predictable, spatially concentrated, and productive resource that can be stored for later use with appropriate facilities (Partlow, 2000). Therefore, because salmon are seasonally concentrated in productive riverine locations, they are a defendable resource (e.g. Coupland, 1988). However, the defense of a salmon procurement site is costly as it requires additional individuals who must be fed, housed, and clothed to defend the site. Therefore, individual salmon runs must be productive enough to outweigh the cost of defense. Additionally, the salmon returns must be large enough to outweigh the cost of missed procurement options from other foraging areas (e.g. nearshore marine patches, etc.) (Dyson-Hudson and Smith, 1978). Because salmon runs are annually variable in terms of productivity, timing, and consistency; intensive focus on salmon resources was risky. Because some streams did not possess highly productive salmon runs, salmon intensification was not evident at all places (Schalk, 1977).

Although salmon remains have received the greatest focus by researchers attempting to describe the development of cultural complexity, other marine fish resources (e.g. Pacific cod, rockfish, sculpins, and flatfishes) may also have been intensively used, especially during post-Neoglacial times (Cannon, 1995; Croes and Hackenberger, 1988; Fitzhugh, 1996, 2003; Kopperl, 2001, 2003; Monks, 1987). Because Mink Island is at the mouth of Amalik Bay near productive nearshore marine fishing, marine taxa may have been especially important. Therefore, the role that marine fishes played in the development of resource intensification at Mink Island is also explored.

Four-Stage Resource Depression and Intensification Model

The model employed here was derived from a combination of resource intensification/ depression models developed by Partlow (2000), Fitzhugh (1996, 2003), and Kopperl (2003). The objective is to determine if fish bones may be used to identify temporal changes in resource intensification and depression at the Mink Island site. Additional data derived from

ethnographic sources, site location, site-type, features, and non-fish bone fauna augment interpretations based on the fish bone data. The same general Stages (I-IV) developed by Fitzhugh (1996) and used by Kopperl (2003) are used in this model so inter-regional comparisons may be made. However, Stage IV is divided into three sections (UM II, UM I, and HF.5) so changes in assemblage composition may be tracked at a finer resolution during this transitional period.

Stage I

Stage I dates between 7500 and 4500 cal. BP and corresponds with Ocean Bay I (Kodiak Archipelago) and Takli Alder (Shelikof Strait coast) phases of the Ocean Bay tradition (LM II) (Table 8.1) (Fitzhugh, 1996). Stage I occupants typically resided in small, highly mobile groups near marine resource procurement sites. If a procurement site was especially rich, the occupants may have practiced serial sedentism, where a site was occupied several months before moving. The distribution of the occupants across the landscape during this stage would have been seasonally variable (Fitzhugh, 2003). Because the landscape was largely devoid of other hunter-gatherer groups, we would not expect to find evidence of repeated use of archaeological sites except in extremely productive areas (Fitzhugh, 1996, 2003).

The resulting archaeological evidence of serial sedentism includes thin, but potentially dense, archaeological deposits near resource procurement areas. Evidence for substantial house structures that were designed to be inhabited longer than several months should be absent from Stage I sites. Additionally, storage pits, drying racks, and smoke houses should be rare during this stage, which indicates a lack of intensification (Fitzhugh, 1996).

Faunal assemblages should reflect a generalized strategy, they should be diverse and mixed but dominated by large-bodied, high-ranked prey (e.g. sea mammals), that were easily processed (Hausler-Knecht, 1993). Mixed fauna were captured during periods while waiting for high-ranked prey items to present themselves, and therefore may be quite numerous. The associated organic and lithic tool kits should be generalized (e.g. harpoons, fishhooks, microblades, cores, bifaces, scrapers, hammerstones, abraders, and stone oil lamps), which also reflects a generalized procurement strategy. Recovered faunal assemblages from this stage

should be from thin midden deposits and associated artifact densities should be low, reflecting the short duration of occupation (Fitzhugh, 1996, 2003).

Stage II

Stage II dates between 4500 and 2800 cal. BP and corresponds roughly with Ocean Bay II (Kodiak Archipelago), Takli Birch (Shelikof Strait coast), and Brooks River Strand (Bering Sea slope) phases of the Ocean Bay tradition (LM I) (Figure 8.1) (Clark, 1966, 1979; Clark, 1977; Dumond, 1971; Fitzhugh, 1996). The shift to Stage II occurred in response to the crowding that occurred across the landscape at the end of Stage I. Increased population pressure resulted in the utilization of all of the most productive procurement sites, which depressed prey populations and limited mobility options (Fitzhugh, 1996). Because of the increased population and associated constrained mobility, Stage II archaeological sites should have higher densities, contain higher frequencies of multiple occupations, and express higher degrees of site modification (Fitzhugh, 1996). Small, tent-covered house structures may be expected to be present at some Stage II sites. However, storage pits, drying racks, and smoke houses should be rare during this stage (Fitzhugh, 1996).

Decreased mobility would have caused increased harvest pressure on large-bodied prey (e.g. sea mammals) and caused resource depression. To overcome problems associated with resource depression, Stage II occupants may have employed a labor intensification strategy by spending more time and energy in pursuit of the large-bodied, high-ranking prey. Additionally, occupants may have employed a food sharing strategy where the effects of short-term variability in harvest returns were buffered by sharing (Kopperl, 2003).

Archaeological expression of labor intensification should include increased numbers of toggling harpoons, floats, and throwing boards as they improve hunting efficiency (Fitzhugh, 1996). Faunal assemblages associated with Stage II should show evidence of resource depression. Stage II sea mammals and other fauna (especially marine fishes) should be composed of smaller and younger individuals (e.g. have shorter fork lengths) as compared to those associated with Stage I times (Fitzhugh, 1996).

Stage III

Stage III dates between 2800 and 900 cal. BP and corresponds with Early Kachemak, Late Kachemak (Kodiak Archipelago); Takli Cottonwood, Kukak Beach (Shelikof Strait coast); Smelt Creek, Brooks River Weir, and Brooks River Falls (Bering Sea Slope) phases of the Kachemak/Norton sub-traditions (UM III) (Figure 8.1) (Clark, 1966, 1979; Clark, 1977; Dumond, 1971, 2005; Fitzhugh, 1996). The shift towards the Stage III strategy occurred in response to the combined effects of population pressure and resource depression (Fitzhugh, 1996). The Stage III strategy employs technological intensification to alleviate the problems of feeding increasing numbers of individuals in an environment composed of increasingly depressed resources. Because of the strategic shift during Stage III, occupants became more sedentary and permanent villages begin to show up in the archaeological record.

Technological intensification allowed the regional occupants of Stage III to overcome some of the problems associated with reduced mobility. New technologies and associated labor divisions were developed to increase harvesting and processing efficiency of small-bodied prey (e.g. fishes and birds). This type of subsistence strategy would be considered risky on an individual level without the cooperation of other group members. However, when small-bodied prey (especially salmon) are harvested in large numbers with the aid of the entire group, the strategy becomes quite profitable. Certain parties captured the salmon, while other parties processed and stored them for later consumption. New technologies that were developed for the mass capture (e.g. nets, weirs, traps, etc.), processing (e.g. ulus, cooking receptacles, etc.), and storage (pits, drying racks, smoking huts, etc.) of salmon increased their overall ranking and allowed this strategy to thrive (Fitzhugh, 1996; Kopperl, 2003).

Archaeological evidence for technological intensification is visible within the faunal assemblage as decreasing faunal diversity and increasing numbers of fishes (especially salmon) and birds. The specialized procurement strategy is also visible within the tool kit, as tools become more specialized (technological intensification) and typologically diverse (Fitzhugh, 1996). Tools used to procure and process mass-harvested resources (small-bodied prey) will also rise in number. Processing tools will outnumber hunting/procuring tools under this strategy (Fitzhugh, 1996).

The result of technological intensification associated with Stage III is increased foraging efficiency. The increased foraging efficiency may have caused human populations within the region to increase substantially. Therefore, group sizes are expected to grow during this stage. Additionally, inter- and intra- group political competition and conflict are expected to increase (Fitzhugh, 1996). The archaeological expression of these phenomena should be visible as a proliferation of artistic and exotic crafts. Additionally, there should be an increase in the evidence of localized warfare (e.g. defensive sites, elaborate weapons, and evidence of trauma on skeletons) (Fitzhugh, 1996).

Stage IV

Stage IV dates between 900 and 200 cal. BP and corresponds roughly with Koniag (Kodiak Archipelago); Kukak Mound (Shelikof Strait coast); and Brooks River Camp, Brooks River Bluffs, and Pavik (Bering Sea slope) phases of the Thule/ Koniag traditions (UM II, UM I, HF.5) (Figure 8.1) (Clark, 1966, 1979; Clark, 1977; Dumond, 1971; Fitzhugh, 1996). Within Stage IV, there is a distinct shift towards a focus on competition and defense (Fitzhugh, 2003). Population growth, technological intensification, storage, and increased competition between groups leads to unequal distribution of productive resources areas and goods.

Village sites are expected to decrease in number during Stage IV. Villages near less-productive procurement zones were abandoned and those near highly productive areas expanded (sometimes dramatically) in size (Fitzhugh, 1996). Individual houses within those large settlements increased in size to incorporate larger kin groups. The larger ranked settlements, therefore, contained the greatest number of large houses (Fitzhugh, 1996).

The large-bodied high-ranking prey items (e.g. sea mammals) that became depressed during the first two stages of this model, may have had the opportunity to rebound during the last stage, when efforts where shifted towards the mass harvest of small-bodied prey items (e.g. salmon, marine fishes, and birds) (Kopperl, 2003). Although hunting sea mammals during Stage IV would still be considered sub-optimal and risky compared to the mass harvesting of small-bodied prey items, it may be reproductively advantageous for some individuals within a group to assume the risk (Hawkes, 1993; Hildebrandt and McGuire, 2002; Kopperl, 2003). This risky

activity provided those individuals who lacked control over the defendable and predictable resources such as salmon runs, a means to achieve prestige. Those individuals who control access to salmon runs tolerated subordination (e.g. hunters engaged in risky behavior) because the activity provided additional resources that were then re-distributed throughout the group (Fitzhugh, 1996). Despite the prevalence of high-risk hunting, the bulk of the faunal materials recovered from Stage IV archaeological components should reflect the dominance on small-bodied, mass-harvested prey (e.g. technological intensification). Resource specialization should be evident in the harvesting and processing technologies, facilities (large houses, storage pits), and marine faunal assemblages (Fitzhugh, 1996).

Large-scale warfare should also be visible within the archaeological record during Stage IV. Defensive sites should begin to show up in the archaeological record in village localities and in procurement sites (e.g. salmon streams). There should also be an increase in evidence of trauma on skeletons, as competition over resources would become common. Evidence for social stratification should be present in the form of increased numbers of elaborately decorated non-utilitarian trade goods (Fitzhugh, 1996).

Table 8.1. Model stages, temporal/cultural zones, traditions/phases, and calibrated radiocarbon age ranges (2-sigma).

Model Stage	Temporal/ Cultural Zones	Tradition/ Phase	Radiocarbon Age Ranges for Stages
I	LM II	Ocean Bay I	7500-4500 cal. BP
II	LM I	Ocean Bay II	4500-2800 cal. BP
III	UM III	Norton/Kachemak	2800-900 cal. BP
IV	UM II	Thule/Koniag	900-750 cal. BP
	UM I	Thule/Koniag	750-600 cal. BP
	HF.5	Developed Thule/Koniag	640-510 cal. BP

Available Fish Taxa and their Associated Habitats

The prehistoric occupants of the Shelikof Strait coast had access to abundant marine and riverine species of fishes. Although some marine fishes (e.g. greenlings, small flatfishes, juveniles of many taxa, etc.) could be easily captured from land (e.g. on craggy outcrops, on

islands in the mouth of bays, etc.), most taxa (e.g. Pacific cod, sculpins, large flatfishes, lingcod, etc.) were most easily caught from boats. Descriptions of several important fish taxa (and associated habitat and season of availability data) that were regularly caught in the waters surrounding Mink Island are presented in Table 8.2. Fishing for these marine fish taxa could yield large individuals, however, the costs of maritime travel and limited cargo space had to be considered. The procurement of anadromous fish resources (e.g. salmon) from riverine environments on the Alaska Peninsula mainland may have also yielded large net energy returns. With proper technological innovations, salmon may have been mass-harvested and stored for later use. As salmon were only available on a seasonal basis, the costs of harvesting, processing, and storing must be factored into the equation. The costs of fishing for marine species (long-line construction and maintenance, harvesting, processing, travel, limited cargo space) was much less compared to the costs of fishing for riverine species (net and weir construction and maintenance, harvesting, processing, storing, defense of resource patch) (Mishler, 2001).

Marine fish taxa most often associated with archaeological sites along the Shelikof Strait coast and in the Kodiak Archipelago are dominated by fishes such as Pacific cod, Pacific halibut, other flatfishes, sculpins, rockfish, greenlings, and Pacific herring (Kopperl, 2003; Partlow, 2000). Pacific cod occupy waters that average 70 meters deep during the spring and summer months and move off shore to spawn in water that averages 120 meters deep during the winter months (Rogers *et al.*, 1986). Although Pacific cod are most readily available during the spring when they congregate shallow nearshore waters, they may be caught year-round during good weather. Because of the year-round access, Pacific cod were typically not dried for winter storage (Davydov, 1977). Pacific cod were captured from kayaks using compound fishing hooks and kelp line approximately 50 fathoms (300 feet) long with a stone weight attached (see Chapter 4, Figure 4.11) (Haggarty *et al.*, 1991; Holmberg, 1985). As rotting fish heads were highly prized as a delicacy, the cod were captured as not to damage the head (Davydov, 1977).

Table 8.2. Scientific name, common name, habitat, seasonal availability of marine and riverine fish taxa. Adapted from Fitzhugh, 2003 (Tables 2.4 and 2.5; Pp. 26-28). Sources from Barsch, 1985; Kessler, 1985; Mecklenburg *et al.*, 2002; Ropell, 1982).

Scientific Name	Common Name	Habitat	Seasonal Availability
Hippoglossus stenolepis	Pacific halibut	continental shelf and on floors of deep bays	Late spring to fall (juveniles year-round)
Gadus macrocephalus	Pacific cod	continental shelf and on floors of deep bays	year-round
Eleginus gracilis	saffron cod	floors of shallow and deep bays	year-round
Theragra chalcogramma	walleye pollock	continental shelf and on floors of deep bays	year-round
Sebastes spp.	Rockfish	inshore and coastal distributions	year-round
Clupea pallasii	Pacific herring	schools nearshore during spawning	year-round (spring-spawning)
Platichthys stellatus	Starry flounder	in shallow waters near mouths of rivers and streams	year-round
Limanda aspera	yellowfin sole	common in waters less than 50 fathoms	year-round
Lepidopsetta polyxystra	Northern rock sole	continental shelf and on sand bottoms	year-round
Ophiodon elongatus	Lingcod	near the bottom of rocky areas, reefs, and kelp beds	year-round
Cottidae (family)	Sculpins	shallow water	year-round
Pleurogrammus monopterygius	Atka mackerel	kelp beds	early spring and summer
Hexagrammos spp.	Greenlings	inshore and coastal distributions	year-round
Oncorhynchus spp.	Salmon	Fresh water lakes and streams	late spring to fall

Pacific herring concentrate in shallow bays during the months spanning from June to November (Rogers *et al.*, 1986). Pacific herring were especially important to the Alutiiq peoples of Prince William Sound (Haggarty *et al.*, 1991). It remains unclear how important Pacific herring were to the prehistoric occupants of the Shelikof Strait coast. However, Pacific herring

have extremely small and fragile bones that often are not collected from archaeological sites using standard 0.64 cm (1/4 in) sieve sizes (see Chapter 6).

Halibut move offshore during the winter months in waters ranging from 300 to 1000 meters (Haggerty *et al.*, 1991; OCSEAP staff, 1986), but may be captured in near shore locations during the summer (Rogers *et al.*, 1986). Halibut were typically caught using long-lines with V-shaped wooden hooks attached to the end; however, they were sometimes speared in shallow nearshore locations (Haggarty *et al.*, 1991).

Although salmon are briefly congregated in bays and near the mouths of rivers along the Shelikof Strait coast, prehistoric occupants of the region typically harvested the salmon after they entered rivers (Davydov, 1977; Holmberg, 1985). The riverine focus for salmon fishing efforts is supported by archaeological sites along rivers that contain major salmon runs (Jordan and Knecht, 1988; Dumond, 2005). Chinook salmon (*Oncorhynchus tshawytscha*) were the first to spawn in late spring, pink (*Oncorhynchus gorbuscha*), chum (*Oncorhynchus keta*), and sockeye (*Oncorhynchus nerka*) followed during the summer months, and coho (*Oncorhynchus kisutch*) spawned during late summer and fall (Roppell, 1986).

Near-Shore Marine and Riverine Resource Patches

For the purposes of this dissertation, the testing of the resource depression and intensification model is limited to the near-shore marine and riverine patches. Although the prehistoric occupants of the region most certainly used terrestrial resource patches to collect plants and as travel corridors, they are not considered here because fish resources generally were not acquired from this patch. Additionally, the off-shore marine patch is not considered in this dissertation because the costs of travel outweigh the returns in this environment, and therefore this patch was generally not affected by resource depression. Although the prehistoric occupants of the region consumed sea mammals, birds, shellfish, and terrestrial mammals (e.g. Hausler-Knecht, 1993; Murray, 2004a), gathered from near-shore marine and riverine resource patches, they are not integrated into this model of resource depression.

Near-shore marine resource patches are composed of beaches, sea stacks, and rocky reefs that are accessible from shore; and bays and other open water areas that are accessible by

boat (Crowell *et al.*, 2003; Fitzhugh, 1996). Smaller-bodied and less diverse marine fish taxa and juveniles of larger taxa would have been accessed from beaches and larger-bodied and more diverse marine fish taxa would have been captured in near-shore areas accessible by boat. Fishing in boat-accessed near-shore marine patches would have likely occurred while waiting for larger-bodied sea mammals (especially Steller sea lions near Mink Island) to present themselves. It would not be unheard of for a foraging party to return to the central foraging locality with marine fishes and without sea mammals (Kopperl, 2003). Although the types of taxa available for capture differed seasonally, the near-shore fishing habitat yielded fishes on a year-round basis (Table 8.2) (Kramer and O'Connell, 1995; Kramer *et al.*, 1995; Mecklenburg *et al.*, 2002; Rogers *et al.*, 1986).

Riverine patches are exploited from the mouths of rivers and along their banks. The great seasonal concentrations of salmon attracted the prehistoric occupants of the region annually. The occupants captured large numbers of salmon seasonally using nets and weirs and processed their catch for storage along the banks and mouths of these rivers (Hoffman *et al.*, 2000). Salmon were captured with whale-sinew nets stretched across rivers and by spearing them at stone or wooden weirs (Davydov, 1977; Holmberg, 1985). Coho salmon were preferred for drying because they were late spawners and contained less fat, which made them easier to dry (Knecht, 1995). Riverine patches would have been exploited during salmon runs from May through September. The timing of the runs varied depending on the size of the rivers, if the rivers were part of a river-lake system, and species of salmon (Hoffman *et al.*, 2000).

Resource Depression and Intensification Model Predictions

The resource depression and intensification model employed here predicts that the occupants of the Shelikof Strait coast utilized resource patches that provided the highest energetic returns for a specific technology during all stages. Nearshore marine patches were used when sea mammals and large fishes were available. Associated technologies were aimed at procuring individual animals (e.g. harpoons for sea mammals and compound hooks for large fishes) (McCartney *et al.*, 1998). Encounter rates with sea mammals and larger fish (especially Pacific cod) declined in association with increased harvest pressure connected with growing

human population in the region (Charnov, 1976; Charnov *et al.*, 1976). The pattern of increased harvest pressure corresponds with Stage II of the resource depression model, and is associated with the Ocean Bay tradition (Ocean Bay II) (Kopperl, 2003).

As harvesting pressure associated with greater human population growth resulted in decreased encounter rates (with sea mammals and large fishes) in the nearshore marine patch, the patch choice model predicts that humans would turn to a more productive resource patch. Occupants would exploit lower-return and higher- cost (lower-ranking) resource patches (e.g. riverine patches along the Shelikof Strait coast) and more distant high-return high-cost nearshore marine resource patches (Erlandson *et al.*, 1992; Fitzhugh, 1996, 2003; Kopperl, 2003). This shift in resource patch focus is associated with the transition to Stage III and corresponds to the Kachemak tradition (Fitzhugh, 1996). Settlement patterns change during this stage, with houses clustering around the mouths of streams, along beaches, and at the confluence of lakes and streams (Dumond, 2005). The archaeological materials associated with Stage III convert from high-ranked prey types (e.g. sea mammals) to lower-ranked prey types (e.g. salmon and marine fishes). Among fishes (especially Pacific cod), there should be a decrease in size and age over time (also reflecting resource depression) (Kopperl, 2003).

The focus on the riverine patched would not occur until the salmon harvesting technology changed. Without the necessary technological innovations (e.g. nets, weirs, ulus, etc.), the net energetic return of salmon would not exceed those of sea mammals. Technological innovations helped reduce procurement and processing costs, and therefore salmon became increasingly important and achieved a higher rank (Winterhalder and Goland, 1997). Evidence for technological innovations associated with salmon procurement includes net weights (see Chapter 4, Figure 4.14) that first appear on Kodiak Island sites during the Early Kachemak phase (Kopperl, 2003). Evidence of nets are absent from the Mink Island site as there is a ca. 2000-year occupational hiatus during this stage (Hilton, 2002). Other sites were occupied along the Shelikof Strait coast during this period (Schaaf, 2011, personal communication).

The technological innovations that occurred during the Kachemak tradition set the stage for cultural complexity to emerge in the region. Differential access to mass-harvested salmon resulted in social inequality during the end of Kachemak tradition. Social inequality became more distinct at the beginning of the Koniag/Thule traditions, which marks the transition to

Stage IV. Competition over the salmon resources resulted in behavioral changes. Individuals who had access to productive salmon procurement locations engaged in prestige seeking behaviors (e.g. food redistribution, political competition) (Fitzhugh, 2003). Individuals who lacked access to salmon often engaged in subordination behaviors (e.g. risky sea mammal hunting) during Stage IV (Fitzhugh, 2003).

Throughout the remaining chapter, two of the basic optimal foraging theory models (prey choice/diet breadth and patch choice/marginal value theorem) are used to test the hypothesis that resource depression and intensification occurred along the Shelikof Strait coast. While this dissertation does not explicitly test any models of cultural complexity, it measures how Fitzhugh's (1996, 2003) broad cultural complexity model developed for the Kodiak Archipelago relates to subsistence choices and resource intensification along the Shelikof Strait coast.

Research Questions and Hypotheses

Research Question 6: Did Mink Island Occupants target specific fish taxa, and if so, did those taxa vary in relation to season, climate zones, and procurement methods?

Null Hypothesis 6 (Assessed qualitatively): Mink Island occupants did not target specific taxa and those taxa did not vary in relation to season, climate zones, and procurement methods.

Research Question 7: Is there evidence of resource depression(s) at Mink Island, as indicated by a reduction in Pacific cod fork lengths, and if so, is climate a forcing mechanism?

Null Hypothesis 7a: Fork lengths do not differ significantly across temporal/cultural zones. H_o: $p \geq .05$

Null Hypothesis 7b: Fork lengths do not differ significantly across climate zones. H_0: $p \geq .05$

Alternate Hypothesis 7a: Fork lengths differ significantly across temporal/cultural zones. H_a: $P < .05$

Alternate Hypothesis 7b: Fork lengths differ significantly across climate zones. H_a: $p < .05$

Research Question 8: Is there evidence of resource intensification, as indicated by an increase in salmon abundance (Salmon Index), a decrease in evenness (Shannon Index of Evenness), and evidence of storage (as determined by skeletal element representation), among the Mink Island temporal/cultural zones?

Null Hypothesis 8a: There is no evidence of increasing salmon abundance (Salmon Index) among the temporal/cultural zones at Mink Island. H_o: $p \geq .05$

Null Hypothesis 8b: There is no evidence of decreasing evenness (Shannon Index of Evenness) among the temporal/cultural zones at Mink Island. H_o: $p \geq .05$

Null Hypothesis 8c: There is no evidence of storage (as determined by skeletal element representation) among the temporal/cultural zones at Mink Island. H_o: $p \geq .05$

Alternate Hypothesis 8a: There is evidence of increasing salmon abundance (Salmon Index) among the temporal/cultural zones at Mink Island. H_a: $p < .05$

Alternate Hypothesis 8b: There is evidence of decreasing evenness (Shannon Index of Evenness) among the temporal/cultural zones at Mink Island. H_a: $p < .05$

Alternate Hypothesis 8c: There is evidence of storage (as determined by skeletal element representation) among the temporal/cultural zones at Mink Island. H_a: $p < .05$

Results: Taxonomic Diversity and Abundance

Results presented in this chapter are organized as follows: LM II corresponds to Stage I (Ocean Bay I), LM I corresponds to Stage II (Ocean Bay II), UM III corresponds to Stage III (Norton/Kachemak), and UM II, UM I, and HF.5 correspond to stage IV (Thule/Koniag) of the resource depression and intensification model. UM II, UM I, and HF.5 are separated here to obtain a more refined timing of the development of resource intensification. The fish remains analyzed were recovered from the LM (Lower Midden), UM (Upper Midden Column Sample), and HF.5 (House Feature 5) contexts. Although the HF.5 radiocarbon dates place it within UM I time span (e.g. 750-455 cal. BP), it is separated here because it was not recovered from the column sample locus (see Figure 4.5 for a plan-view of the loci). HF.5 represents one of the most recent occupations at Mink Island, and it may therefore, help to refine the timing of the development of resource intensification at Mink Island. The HF.5 assemblage (from unit 7S13E) is comprised of midden materials and is not directly associated with a house floor, although the label HF.5 is misleading, it is used here for consistency.

The results of the taxonomic diversity and abundance analysis of Mink Island fish taxa are presented in this section. The goal is to determine if taxa abundance and composition changed over time as predicted for the model stages outlined in this chapter. The results are presented by family, so that changes in general patterns of diversity and abundance may be explored.

The examination of change over time of taxonomic diversity is explored using the NISP abundance measure. NISP and %NISP values for the temporal/cultural zone assemblages are presented in Table 8.3 and Figure 8.1, respectively. Because the fauna from the temporal/cultural zones were collected using different recovery and sampling strategies, they possess highly variable sum NISP values. The UM I, UM II, and UM III assemblages were obtained from a column sample (20x20 cm) whereas the LM I and LM II assemblages were collected from a block excavation (16x16 m). Additionally, the HF.5 assemblage represents a random sample (ca.2.5%) recovered from a 1x1m excavation unit (7S13E), whereas the remaining assemblages (UM and LM) were analyzed in entirety (100%). Therefore, comparisons

in abundance between the assemblages have been normalized, and %NISP values are used to describe differences in abundance.

The LM II assemblage (Stage I, Ocean Bay I) is dominated (60%) by small members of the family Pleuronectidae (mainly starry flounders, rock soles, butter soles, and flathead soles) (Figure 8.1). Gadidae (mainly Pacific cod but also walleye pollock) comprise 14%, Salmonidae (salmon) are 13%, Cottidae (Irish lords and great sculpins) compose 11%, Hexagrammidae (rock greenlings, Atka mackerel, and lingcods) constitute 1 %, and Scorpaenidae (rockfish) and Clupeidae (Pacific herring) each compose less than 1 % of the assemblage. The low overall abundance of the fish bone assemblage (NISP=1930) demonstrates that fishes were not the procurement focus of Mink Island occupants during this period. The small flatfishes were likely captured from shore (beach) locations where small flatfishes are easily procured on a year-round basis (Rogers *et al.*, 1986). Climatic conditions associated with Stage I are warmer and drier compared to those associated with all of the other stages (II, III, IV). Stage I is associated with the transitional period after the Hypsithermal (ca.11,000 -9000 cal. BP) (Kaufman *et al.*, 2004) and before the development of the Neoglacial period.

There is a dramatic shift in taxonomic composition associated with the shift to LM I (Stage II, Ocean Bay II) (Figure 8.1). Members of the family Pleuronectidae (mainly rock soles, flathead soles, yellowfin soles, and starry flounders), which composed 60% of the previous assemblage, compose only 7% of the LM I assemblage. Gadidae (mostly Pacific cod but also walleye pollock) comprise 46% of this assemblage, Cottidae are 30%, Salmonidae constitute 15%, Hexagrammidae (rock greenlings, Atka mackerel, and lingcod) comprise 1%, and Clupeidae and Scorpaenidae each are less than 1% of the assemblage. The shift towards a dominance of Pacific cod and sculpins likely reflects a shift in the resource patches that were used. These fishes were likely captured from nearshore marine resource patches using hook and line while waiting for sea mammal procurement opportunities. These fish taxa would have been available on a year-round basis, but would have been more easily captured during the spring and summer months (Rogers *et al.*, 1986). The marked increase in NISP values (compared to the LM II assemblage) reflects the greater importance placed on fish resources during this period. The climatic conditions during this period reflect the beginning of the Neoglacial period, which is marked by cooler, wetter, and stormier conditions (Crockford and Frederick, 2007). The

increase in abundance of Pacific cod and walleye pollock during this stage is likely not related to the changing climatic conditions. Proxy fisheries data indicates (see the later resource depression section) that Pacific cod and walleye pollock abundance should decrease in relation to cooling climatic conditions (e.g. Anderson and Piatt, 1999).

The UM III assemblage (Stage III), which is separated by more than 2500 years from the LM I assemblage, is dominated by members of the family Gadidae (55%) (mainly Pacific cod but also walleye pollock and saffron cod) (Figure 8.1). The next most abundant family, Cottidae (Irish lords and great sculpins), compose 23% of the assemblage. Flatfishes (mainly flathead soles, Pacific halibut, rock soles, and yellowfin soles) comprise 9%, Salmonidae constitute 9%, Clupeidae are 3%, Scorpaenidae comprise 1%, and Hexagrammidae (rock greenling and Atka mackerel) are less than 1%. The increase in Pacific cod and sculpins indicates that the Mink Island occupants used hook and line technology and were focused on nearshore marine habitats during Stage III. The pattern reflects a general trend during the Norton/Kachemak period towards procuring lower ranked prey items (e.g. fishes) from high-ranked resource patches (nearshore marine). However, there is no evidence that the occupants shifted focus towards utilizing lower-ranked riverine resource patches along the Shelikof Strait coast (salmon only comprise 9% of the assemblage). The climatic conditions reflect the transitional period between the end of the Neoglacial period and the beginning of the Medieval Warm Period. Therefore, climatic conditions would likely favor a mixture of marine and riverine fish taxa, which would have been available on a year-round basis (Rogers *et al.*, 1986) (Table 8.2).

The same general pattern associated with the UM III assemblage continues with the UM II assemblage (Stage IV), however, the trend towards increasing numbers of Gadidae and Cottidae is amplified (Figure 8.1). Gadidae (mostly Pacific cod) comprise 61% of the assemblage, Cottidae (Irish lords and great sculpins) are 28%, Salmonidae (salmon) compose 6%, Pleuronectidae (mainly flathead sole, butter sole, and rock sole) constitute 4%, and the remaining families (Clupeidae, Hexagrammidae, and Scorpaenidae) each are less than 1% of the assemblage. Because Pacific cod and sculpins constitute 89% of the entire UM II assemblage, it is evident that the Mink Island occupants used hook and line technology and focused their foraging efforts on the nearshore marine resource patches. The reduced abundance of salmon (6%) suggests that riverine habitats on the Shelikof Strait coast were not targeted. This pattern

does not match the model expectations, which predicts that Stage IV is associated with increasing use of riverine patches and higher salmon abundance. Therefore, the fishbone data indicate that the transition into the Stage IV strategy did not occur at Mink Island during UM II (1000-750 cal. BP). The climatic conditions associated with the UM II assemblage are linked with the Medieval Warm Period (Solomon *et al.*, 2007), which is marked by warm and dry conditions. Although the warm and dry conditions promote Pacific cod abundance, they do not promote Irish lord abundance; therefore, the pattern suggests that climatic conditions were likely not the primary factor responsible for structuring the fish bone assemblage. The pattern likely reflects the use of nearshore marine resource patches on a year-round basis.

There is a sharp decrease (18%) in the number of Gadidae (Pacific cod) associated with UM I (Figure 8.1). The associated increase in Cottidae (Irish lords and great sculpins) (48%) during this temporal/cultural zone is just as sharp. Salmonidae numbers also increase (17%), as do Clupeidae (13%). Flatfishes (yellowfin sole) compose 4%, and Hexagrammidae (rock greenling) comprise less than 1% of the assemblage. The increase in sculpins, salmon, and herring coupled with a decrease in Pacific cod indicates a shift in resource patch use. Mink Island occupants continued to use hook and line technology but shifted their focus from more distant nearshore marine patches to those located closer to shore. Herring would have been captured in spring in intertidal and shallow subtidal waters (Rogers *et al.*, 1986). Although there is some evidence that riverine patches (along the Shelikof Strait coast) were utilized (salmon compose 17% of the assemblage), they were not intensively focused on. Salmon would have had to constitute a larger percentage of the assemblage to indicate resource intensification. Therefore, the data lead to the conclusion that the transition into the Stage IV strategy did not occur at Mink Island during UM I (750-455 cal. BP). The climatic conditions associated with the UM I assemblage are linked with the development of the Little Ice Age, a period of increasingly cooler and wetter conditions (Mann, 2003). Although the Little Ice Age may have developed half way through the UM I period (e.g. 550-400 cal. BP), the bulk of the faunal materials from this UM I assemblage are dated at ca.535 cal. BP (see Chapter 4). The composition of the UM I fish bone assemblage does not conform to what would be expected if cooler and wetter climatic conditions were responsible for structuring the assemblage. Therefore, the pattern suggests that Mink Island occupants fished from beaches. Although the fish taxa would have been

available year-round, the increased number of salmon and herring indicate that fishing was concentrated during the spring and summer months.

Finally, the HF.5 assemblage demonstrates a marked increase in Salmonidae 42% (Figure 8.1). There is also an increase in Gadidae [almost evenly split between Pacific cod (NISP=856) and saffron cod (NISP=742)] (34%). Cottidae (Irish lords and great sculpins) decrease in number (15%), as do Clupeidae (7%), Pleuronectidae (mainly Pacific halibut) (2%), Scorpaenidae (less than 1%), and Hexagrammidae (rock greenling, lingcod, Atka mackerel) (less than 1%). Osmeridae (eulachon) are also present in the HF.5 assemblage, composing less than 1% of the assemblage. The HF.5 pattern is different from the other Mink Island assemblages. The large percentage of salmon indicates that Mink Island occupants used riverine resource patches (along the Shelikof Strait coast) during this period. However, because salmon constitute less than half of the analyzed fish bone assemblage, it does not indicate that they were exploited at the expense of other foraging opportunities. Rather, the data indicate that the occupants practiced a mixed procurement strategy that utilized hook and line technology and focused on small-bodied prey items (fish) that were captured from a mixture of nearshore marine and riverine resource patches. Salmon were captured during the spring and summer using net and weir technology from riverine resource patches and the remaining taxa may have been captured using hook and line technology throughout the entire year from marine resource patches. The climatic conditions associated with the HF.5 assemblage are associated with the Little Ice Age, a period of cooler and wetter conditions (Mann, 2003).

Table 8.3. NISP values of family-level taxonomic identifications associated with the Mink Island temporal/cultural zones. Radiocarbon age ranges are calibrated (2-sigma)

Taxon	HF.5 640-510 BP)	UM I (750-455 BP)	UM II (1000-750 BP)	UM III (1600-1000 BP)	LM I (5400-4100 BP)	LM II (6700-5400 BP)
Clupeidae	334	28	7	40	8	4
Cottidae	741	104	339	346	1667	204
Gadidae	1690	38	746	845	2526	265
Hexagrammidae	9	1	3	7	66	26
Osmeridae	3	0	0	0	0	0
Pleuronectidae	101	8	43	141	408	1163
Salmonidae	2129	37	73	137	832	259
Scorpaenidae	12	0	3	21	26	9
Total	**5019**	**216**	**1214**	**1537**	**5533**	**1930**

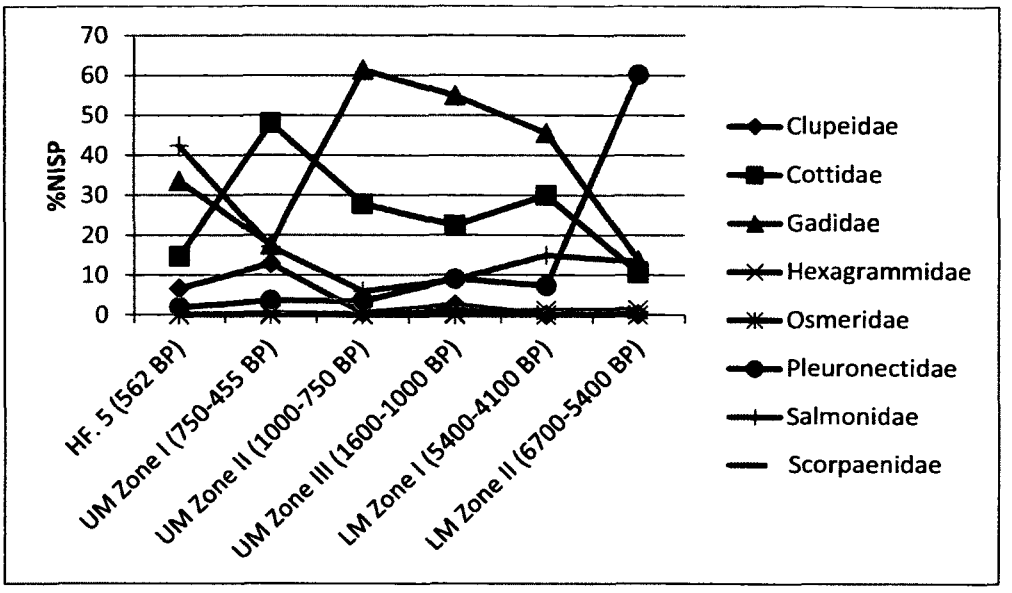


Figure 8.1. Percent NISP values of Mink Island taxa identified to the family-level and aggregated by temporal/cultural zone. Radiocarbon age ranges are calibrated (2-sigma).

The results of minimum number of elements (MNE) analysis are presented for the temporal/cultural zones in Appendix H. MNE is the "minimum number of complete skeletal elements necessary to account for all observed specimes" (Lyman, 1994: 290). MNE is a modification of NISP values that attempts to estimate the number of skeletal elements represented in fragmented bone (Lyman, 2008). MNE values are used here as a stepping stone to obtain %MNI values, which like %NISP, help to identify the relative importance of taxa. Additionally, MNE values are used to determine which taxa were deposited while whole and which ones were deposited in pieces (e.g. cranial bones deposited in separate locations from post-cranial bones).

The family-level MNE data indicate a few general trends (Appendix H). Throughout all temporal/cultural zones Cottidae and Gadidae are represented by relatively complete individuals, which indicates that they were most often discarded whole. Pleuronectidae, demonstrate a variable pattern over time. During LM II, LM I, UM III, and HF.5, Pleuronectidae are represented by relatively complete individuals, however, the pattern changes during UM II and UM I. This pattern is likely a reflection of lowered abundance during UM II and UM I, as associated NISP values range between 43 and 8. Salmonidae are represented by fewer skeletal

elements (mostly post-cranial skeletal elements) during all temporal/cultural zones. This pattern is indicative of differential depositional practices (e.g. evidence for storage), and will be discussed further in a following section. Clupeidae, Hexagrammidae, Osmeridae, and Scorpaenidae are represented by few skeletal elements throughout all temporal/cultural zones. Clupeidae and Osmeridae are each solely represented by vertebrae, which is likely because of preservation biases rather than cultural biases (see Chapter 6).

The MNE data was then used to derive minimum numbers of individual (MNI) values for the temporal/cultural zones (Table 8.4). MNI is a measure of the smallest number of individuals necessary to account for all of the specimens (skeletal elements) of a particular taxon from a given archaeological assemblage (Shotwell, 1955, 1958). White's (1953) method, which uses the most abundant skeletal element from a particular taxon that has been sided (right or left) as the unit of calculation is used here (see Chapter 2).

The MNI values for the family-level taxonomic divisions vary over time. Keeping in mind that the UM assemblage only represents a 20x20 cm bulk sample, associated MNI values will be lower than are their HF.5 (1x1 m) and LM (16x16 m) assemblage counterparts. Because MNI counts are affected by aggregation unit size (Grayson, 1978), their use as a quantification measure is questionable. However, when MNI values are used alongside NISP values, a more robust picture of changing taxonomic diversity becomes visible. The same general patterns (as indicated by %NISP values) of decreasing importance of small flatfishes (Pleuronectidae) coupled with increasing importance of Gadidae (Pacific cod) and Cottidae (sculpins) are visible within the %MNI data (Figure 8.2). The MNI data indicate the same mixed Salmonidae/Gadidae/ Cottidae/Clupeidae assemblage is associated with HF.5.

Table 8.4. MNI values of family-level taxonomic identifications associated with the Mink Island temporal/cultural zones. Radiocarbon age ranges are calibrated (2-sigma).

Taxon	HF 5 (640-510 BP)	UM I (750-455 BP)	UM II (1000-750 BP)	UM III (1600-1000 BP)	LM I (5400-4100 BP)	LM II (6700-5400 BP)
Clupeidae	7	1	1	1	1	1
Cottidae	17	3	7	7	44	5
Gadidae	24	3	10	14	48	6
Hexagrammidae	2	1	1	2	5	4
Osmeridae	1	0	0	0	0	0
Pleuronectidae	4	3	1	3	10	32
Salmonidae	38	3	2	5	9	3
Scorpaenidae	2	0	1	1	4	4
Total	95	14	23	33	121	55

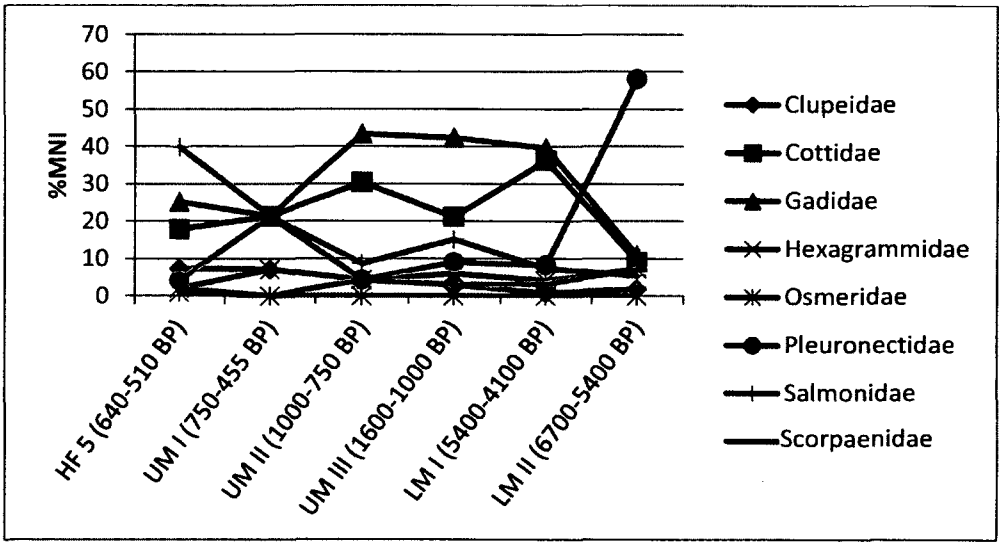


Figure 8.2. Percent MNI values of Mink Island taxa identified to the family-level and aggregated by temporal/cultural zone. Radiocarbon age-ranges are calibrated (2-sigma).

Results from the abundance measures applied to the Mink Island fish bone assemblage (e.g. NISP, MNE, and MNI) indicate change over time in taxonomic diversity. As differing recovery and sampling strategies resulted in differing abundances associated with the temporal/cultural zones, it is not presently possible to track changes in abundance. The results

suggest that the LM II (Ocean Bay I) assemblage fits the resource depression and intensification model. Mink Island occupants likely focused on procuring large-bodied, high-ranked prey (e.g. sea mammals) and small flatfishes (Pleuronectidae) were likely captured (using individual composite hooks) from beaches or other nearshore locations. However, fishes were not the focus of procurement efforts during this stage. A shift in subsistence strategies is seen in the fish bone assemblage associated with LM I (Ocean Bay II), with the marked increase in Pacific cod (Gadidae) and Sculpins (Cottidae). Pacific cod and sculpins were likely captured using individual composite hooks in nearshore marine resource patches while waiting for opportunities to procure high-ranking sea mammals. The same general pattern where nearshore marine patches were the focus of foraging efforts continues through UM III (Stage III, Norton/Kachemak) and UM II (Stage IV, Thule/Koniag). This is the point where the Mink Island assemblage differs from model predictions. The relatively low abundance of salmon remains indicates that Mink Island occupants were not intensively focused on procuring that resource during this stage. Although riverine resource patches were being exploited, they were not the focus during this period (UM II). The shift during UM I (Stage IV, Thule/Koniag), represents the use of more varied resource patches, especially those closer to shore. Finally, the large percentage of salmon associated with HF.5 (Stage IV, Thule/Koniag) indicates that the occupants utilized (through net and weir technologies) riverine resource patches to a greater extent during this period. However, the higher numbers of Pacific herring, saffron cod, Pacific cod, and sculpins indicates that the occupants exploited a mixture of resource patches. Salmon and Pacific herring were captured during the spring and summer months and the remaining taxa were captured throughout the remaining year.

Results: Resource Depression

The results presented in this section are aimed at identifying the timing of resource depression at the Mink Island site. The depletion of high-ranked taxa (e.g. sea mammals) within nearby resource patches may have led the occupants of Mink Island to shift their subsistence strategies during certain periods. Foragers may have intensified their use of lower-ranked taxa (e.g. marine fishes) within high-ranked near-shore patches, they may have exploited lower-

ranked resource patches (e.g. near-by salmon streams), or they may have utilized more distant high-ranked patches that had not been affected by resource depression (Kopperl, 2003). The focus of this research is to determine if lower-ranked taxa (e.g. marine fishes) were more extensively exploited in local near-shore patches.

Changes in reconstructed fork lengths (estimated via linear regression analysis) of marine fish skeletal elements may be used to test the resource depression hypothesis. Fork length data provides information concerning the over-exploitation of lower-ranked marine fish taxa within local high-ranked patches. Those marine fishes that are long-lived (e.g. Pacific cod, halibut, and rockfish) are ideally suited to test the resource depression hypothesis (Moyle and Cech, 1996). These fish taxa grow incrementally and age is strongly correlated with the body size (e.g. fork length) of the living fish (Foucher and Fournier, 1982; Love *et al.*, 2002; Moyle and Cech, 1996). As Pacific cod are the most numerous taxon within the Mink Island assemblage and they are easily identifiable to the species-level, they have been chosen for analysis.

The dimensions of several skeletal elements have been linked to overall fork length through several different methods (e.g. Amorosi, 1987; Casteel, 1976a; Colley, 1990; Orchard, 2003; Rojo, 1986, 1987). The single regression method presented by Orchard (2003) is used here to calculate fork length from measurements of specific Pacific cod skeletal elements. The #3 measurement of the quadrate (Figure 8.3) was chosen for this analysis, because the skeletal element is abundant within the Mink Island assemblage and because the measurement locale (e.g. the mesial and lateral condyles) tends to be well preserved among Mink Island samples.

Figure 8.3. #3 measurement (from Orchard, 2003) of Pacific cod quadrate, used for linear regression analysis. Photograph taken by Rhea Hood, NPS.

A decrease in reconstructed Pacific cod fork length measurements over time may be caused by increased harvest pressure by Mink Island occupants. As harvest pressure increases within a resource patch, the patch becomes depleted (depressed) over time, taxonomic abundance decreases, and mean fork lengths become reduced (Kopperl, 2003; Stephens and Krebs, 1986). The extent to which a resource patch may be depleted will depend on the expected search effort required to locate another resource patch (Charnov, 1976). Additionally, a resource patch may be exploited to sub-optimal levels while waiting for higher-ranked prey procurement opportunities. For instance, Mink Island individuals may have exploited a near-shore marine patch (e.g. marine fishes) to sub-optimal levels while pursuing high-ranking Stellar sea lions. They may not have moved to more productive near-shore marine fishing patches because it would have limited their ability to pursue the higher-ranking Stellar sea lions.

In addition to human harvesting pressure, changes in the abundance and mean fork lengths of Pacific cod (and other marine fishes) may also be linked to temperature changes of the North Pacific Ocean (Anderson and Piatt, 1999). Cooler temperatures are linked with an increase in primary productivity (because of increased nutrient upwelling) (Mecklenburg *et al.*, 2002). However, not all taxa respond favorably to the increase in primary productivity. Anderson and Piatt (1999) conducted a study where trends in catch biomass were analyzed between 1972 and 1997, which corresponded with a climate shift from a cold- to a warm-regime. They determined that yellow Irish lord, herring, greenling, and Atka mackerel abundance decreased in response to warming temperatures. Walleye pollock, flathead sole, Pacific cod, yellowfin sole, arrowtooth flounder, halibut, and rock sole increased during the same warming trend. Eulachon, great sculpin, tomcod, starry flounder, and rockfish varied with respect to the climatic shift (Table 8.5) (Anderson and Piatt, 1999).

These relatively recent shifts in abundance related to a changing climate regime may be used as a guide to predict effects on prehistoric populations. However, because modern commercial fishing efforts undoubtedly affected fish populations (Anderson and Piatt, 1999), it is difficult to make direct comparisons. Therefore, connecting climatic changes with changes in

abundance and fork lengths must be completed with caution. Because a more appropriate approach is lacking, this approach is employed here.

Table 8.5. Warm-water-adapted versus cold-water-adapted fish taxa from the North Pacific Ocean. From Anderson and Piatt, 1999; Pp. 120, Figure 3.

Warm-Water-Adapted	Cold-Water-Adapted	Variable
walleye pollock	yellow Irish lord	eulachon
flathead sole	herring	great sculpin
Pacific cod	greenling	starry flounder
yellowfin sole	Atka mackerel	rockfish
arrowtooth flounder		
halibut		
rock sole		
Alaska plaice		

Several paleoenvironmental proxies have been developed for Alaska and the Northeast Pacific (e.g. Bigelow, 2000; Brubaker *et al.*, 2001; Heusser *et al.*, 1985; Hilton, 2002; Mann *et al.*, 1998; Mason and Jordan, 1993; Misarti *et al.*, 2009; Nelson and Jordan, 1988; Sabin and Pisias, 1996; Wiles and Calkin, 1994; Wiles *et al.*, 1995). Reconstructions from tree rings, glacial geology, oxygen isotopes, stable isotopes (e.g. sediment cores and bone collagen), and pollen cores provide means to reconstruct paleoclimatic conditions. However, because the climatic proxies vary spatially and temporally, they are not always appropriate for comparative purposes.

The climate zones used here were compiled from several local and non-local paleoenvironmental reconstructions (e.g. Crockford and Frederick 2007; Heusser *et al.*, 1985; Kaufman *et al.*, 2004; Mann, 2003; Mann *et al.*, 1998; Solomon *et al.*, 2007). Table 8.6 presents associated model stages, Mink Island temporal/cultural zones, climate zones, climatic conditions, and radiocarbon age ranges. Regional paleoenvironmental reconstructions indicate a warm and dry period between 11,000 and 9000 cal. BP (Hypsithermal) (Kaufman *et al.*, 2004). The warm Hypsithermal conditions are followed by transitional period, which is also warm,

between 9000 and ca.5000 cal. BP (Heusser *et al.*, 1985; Mann *et al.*, 1998; Kaufman *et al.*, 2004). A cool and wet period (Neoglacial) characterized the region between 4700 and 2500 cal. BP (Crockford and Frederick, 2007). There is another transitional period (cool) between the end of the Neoglacial and the beginning of the Medieval Warm Period between 2500 and 1000 cal. BP (Mann, 2003). The Medieval Warm Period is present in the area between 1000 and 750 cal. BP and is characterized by warm and dry conditions (Mann, 2003). There is another transitional period (cool) between the Medieval Warm Period and the Little Ice Age between 750 and 550/400 cal. BP (Mann, 2003). Finally, the Little Ice Age is present in the area by 550/400 cal. BP and lasts until about 50 cal. BP (Solomon *et al.*, 2007).

Table 8.6. Model stages, temporal/cultural zones, climate zones, climatic conditions, and radiocarbon age ranges. Climatic conditions from Crockford and Frederick (2007), Heusser *et al.* (1985); Kaufman *et al.* (2004), Mann (2003), Mann *et al.* (1999), and Solomon *et al.* (2007).

Model Stage	Temporal/ Cultural Zones	Climate Zones	Climatic Conditions	Cal. Radiocarbon Age Ranges (2-Sig)
I	LM II	Transitional	Transitional/warm	5400-4700 cal. BP
II	LM I	Neoglacial	Cold and wet	4700-2500 cal. BP
III	UM III	Transitional	Transitional/cool	2500-1000 cal. BP
	UM II	Medieval Warm Period	Warm and dry	1000-750 cal. BP
IV	UM I	Transitional	Transitional/cool	750-600 cal. BP
	HF.5	Little Ice Age	Cold and wet	640-510 cal. BP

The Little Takli Island pollen data (near Mink Island, see Chapter 3) generally conforms to the four Holocene climate zones (e.g. Hypsithermal, Neoglacial, Medieval Warm Period, and Little Ice Age). The Mink Island site was occupied during the major climate zones as well as during transitional periods whose climatic conditions range from cool to warm (Table 8.6). As Table 8.6. demonstrates, the Mink Island temporal/cultural zones generally conform to the climate zones and are aggregated in the same manner. Therefore, statistical analyses provide the same results, which makes it difficult to distinguish the effects of climate change from the effects of human harvesting pressure on Pacific cod fork lengths. To overcome this problem,

patch choice data will be used in conjunction with the Pacific cod fork length data when inferring evidence for resource depression.

The fork length of seventy-three Pacific cod specimens were calculated using the formula FL = $\alpha + \beta X$. Where α equals 105.19, β equals 56.88, and X is the #3 Pacific cod quadrate measurement (Figure 8.3). FL (fork length) and X are measured in millimeters. The specific values for α and β are based on linear regression analysis of 25 modern Pacific cod individuals captured from the North Pacific ocean (Orchard, 2003: 50). Appendix I displays the #3 measurements and fork length measurements associated with the Mink Island temporal/ cultural zones.

The results are grouped by temporal/cultural/climate zones. Mean fork lengths were not recorded from the LM II (Stage I) assemblage, and therefore are not included here. Although 11 Pacific cod quadrates were recovered from LM II contexts, none of the #3 quadrate measurements were complete, and therefore, could not provide accurate values. The omission of reconstructed fork lengths from the LM II assemblage is regrettable, as it is impossible to determine if resource depression occurred during Stage I (Ocean Bay I). However, the model tested here does not predict that resource depression occurred at Mink Island until Stage II (Ocean Bay II).

The results of one-way ANOVA statistical analysis indicate that mean Pacific cod fork lengths did not differ significantly among the Mink Island temporal/cultural/climate zones (LM I- Neoglacial, UM III- transitional, UM II- Medieval Warm Period, UM I- transitional, HF.5- Little Ice Age) ($F=2.02$; $df= 4, 68$; $p=.101$). Tukey post-hoc comparisons of the temporal/cultural/climate zones; however, indicate that the mean fork length of the UM I assemblage (M=73.16, 95% CI [68.12, 78.20]) is significantly higher than the mean fork lengths of the HF.5 (M=64.93, 95% CI [61.46, 68.40]) and the LM I (M=68.21, 95% CI [60.45, 69.32]) assemblages. Differences in mean fork lengths among the other temporal/cultural/climate zones are not statistically significant at $p<.05$. The large SD values associated with the fork length measurements indicates that Pacific cod fork lengths were highly variable within each of the temporal/cultural/climate zones (Figure 8.4). However, CV values indicate that Pacific cod fork lengths were more variable during the LM I (Stage II) and UM II (Stage IV) temporal/cultural/climate zones (Table 8.7).

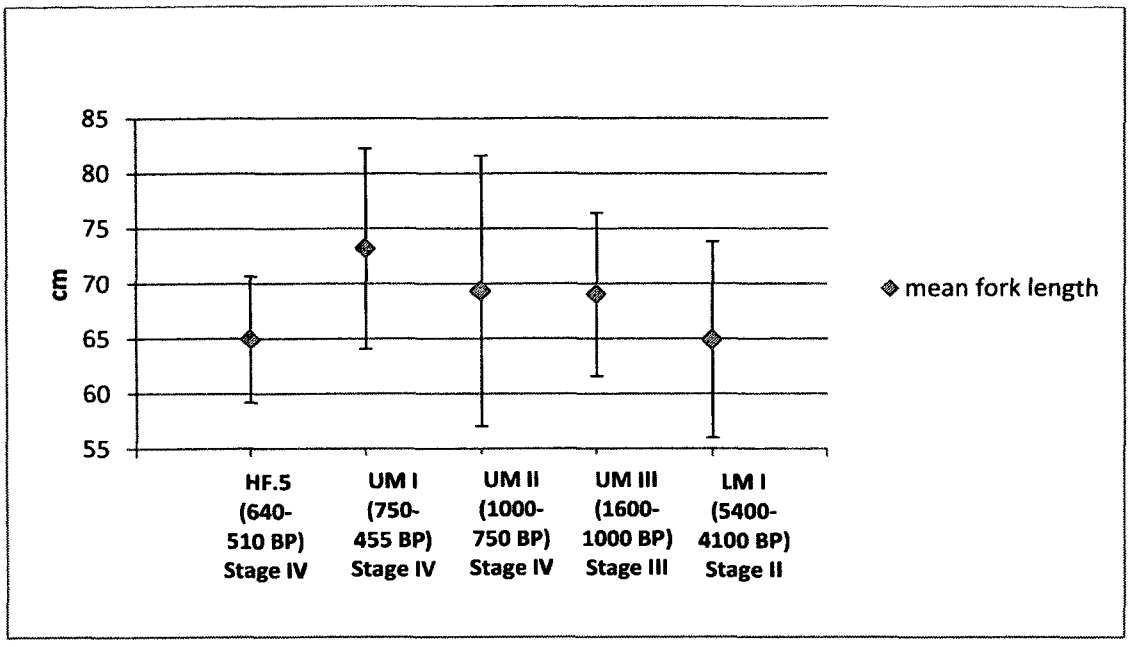


Figure 8.4. Mean fork length and SD values of Mink Island Pacific cod quadrate samples associated with the temporal/cultural zones and model stages. Radiocarbon age ranges are calibrated (2-sigma).

Table 8.7. Mean fork length, SD, and CV values derived from Mink Island Pacific cod samples associated with the temporal/cultural zones and model stages.

Temporal/Cultural Zone	Model Stage	Number of Specimens	Mean Fork Length (cm)	SD	CV (%)
HF.5 (640-510 cal. BP)	IV	13	64.93	5.74	8.84
UM I (750-455 cal. BP)	IV	15	73.16	9.10	12.44
UM II (1000-750 cal. BP)	IV	21	69.32	12.29	17.73
UM III (1600-1000 cal. BP)	III	6	69.01	7.41	10.74
LM I (5400-4100 cal. BP)	II	18	64.88	8.91	13.73

The mean fork length of Pacific cod samples associated with LM I (Stage II, Ocean Bay II) is lower than those associated with all of the subsequent temporal/cultural zones (Stages III-IV). As previously stated, this pattern may be caused by increased harvest pressure by Mink Island occupants, climatic fluctuations, and differences in capture locations. The cooler conditions

associated with Stage II (Neoglacial period) may have affected abundance of Pacific cod and resulted in decreased fork lengths (Anderson and Piatt, 1999). Therefore, It is difficult to separate the effects of human harvesting pressure from climate change as causal factors. If we return to the model predictions for Stage II, the results may be explained. As the population increased and mobility was limited, the productive high-ranked local resource patches around Mink Island became constrained (e.g. Fitzhugh, 1996). As increased harvest pressure on high-ranked prey items (e.g. Steller sea lions at the near-by rookery) resulted in decreased capture opportunities, the Mink Island occupants shifted their focus to lower-ranked prey items (e.g. marine fishes) which were captured within the same near-shore marine patch. Because marine fish were captured while waiting for Steller sea lion harvest opportunities, and the Steller sea lions were congregated in specific rookery and haul-out locations, the Stage II occupants did not move to different near-shore marine patch locations when the marine fishes began to show signs of resource depression (e.g. reductions in abundance and fork length). The Pacific cod populations were concurrently affected by climatic conditions as they became less abundant and more easily affected by human harvesting pressure because of cooler and wetter conditions. Therefore the pattern indicates that less favorable climatic conditions coupled with increased harvest pressure by Mink Island occupants resulted in decreased fork lengths of Pacific cod specimens during Stage II (LM I, Ocean Bay II).

The mean Pacific cod fork length associated with the UM III (Stage III, Norton/ Kachemak, transitional/cool) assemblage is greater than that of the preceding LM I (Stage II) assemblage. The pattern is consistent with the interpretation that climate was the primary factor affecting fork length and associated age distributions during Stage III. A reduction of human harvesting pressure may also have resulted in increased Pacific cod fork lengths. If we return to the model predictions, the shift towards Stage III corresponds with a shift in procurement strategy aimed at alleviating the pressures of resource depression (Fitzhugh, 1996). The Stage III occupants used technological intensification (procurement, processing, and storage) to overcome the problems of feeding increasing numbers of individuals. Additionally, the occupants shifted their focus towards the utilization of small-bodied prey (e.g. fishes) that were captured from low-ranked resource patches (near-shore marine and riverine) (Fitzhugh, 1996). While it may seem counterintuitive that this shift in focus towards marine and riverine

fishes would result in an increase in abundance and fork length rather than a decrease, it is not. There is an apparent occupational hiatus at Mink Island that lasted approximately 2000 years (although there is at least one site dating to this period elsewhere in Amalik Bay, see Chapter 4), during which the marine fish populations had ample time to rebound from the effects of resource depression. Additionally, the Mink Island occupants were no longer limited to capture locations adjacent to Steller sea lion rookeries. The occupants exploited diverse near-shore marine and riverine resource patches without causing resource depression. Therefore, a combination of reduced human harvesting pressure coupled with more favorable climatic conditions resulted in increased mean fork lengths associated with Stage III at Mink Island.

The pattern associated with UM III (Stage III) continues into UM II (Stage IV) at Mink Island. There is a slight increase in mean fork length connected with the Medieval Warm Period (Table 8.6), which is consistent with the interpretation that climate change affected fork lengths. A reduction in human harvesting pressure may have also resulted in increased mean fork lengths. As the model predicts, UM II (Stage IV, Thule/Koniag, Medieval Warm Period) is associated with population growth, technological intensification, increased storage, and increased competition between groups (Fitzhugh, 2003). There should also be an increase in the abundance of salmon within the UM II assemblage, to reduce the harvesting pressure on Pacific cod, which is reflected in increased abundance and fork lengths. Mean fork length values associated with the UM II assemblage are similar to the previous UM III assemblage, which suggests that the Mink Island assemblage does not fit model predictions. Therefore, a combination of human harvesting pressure and climate change may have resulted in increased fork lengths during Stage IV (UM II) at Mink Island.

The UM I assemblage (Stage IV, Thule/Koniag, transitional/cool) is associated with the highest mean Pacific cod fork length value. If climatic variability played the most significant role in dictating abundance and age structures, the Pacific cod fork lengths should be lower associated with this assemblage. However, the opposite pattern is present, indicating that human predation patterns were likely responsible for the increase in fork lengths. The shift towards larger Pacific cod individuals is expected if the Mink Island occupants shifted towards using salmon resources procured from riverine resource patches. Because the marine resources would have received less foraging pressure, the marine fishes would have had time to rebound.

Then, when the near-shore marine resource patches were utilized, larger individuals were harvested.

The HF.5 assemblage (Stage IV, Thule/Koniag, Little Ice Age) provides an interesting pattern in relation to climatic variability. There is a significant decrease in mean fork length in the HF.5 assemblage compared to the UM I assemblage even though they are within the same general temporal zone (e.g. 750-455 cal. BP). Because the depositional environment should not have any bearing on the size of fish that Mink Island occupants were capturing, one of two factors may explain this discrepancy. The occupants of HF.5 may have obtained Pacific cod specimens from nearshore marine locations near salmon streams (see previous section concerning the increase in salmon during this period). As smaller individuals tend to congregate nearer to shore, the smaller mean fork length values may reflect the use of suboptimal resource patches. Alternatively, the decrease in mean fork length may have been caused by climatic change associated with the Little Ice Age. As the radiocarbon dates associated with the HF.5 assemblage (640-510) place it within the Little Ice Age (Hilton, 2002; Mann, 2003), colder temperatures have negatively affected the Pacific cod populations. However, because Pacific cod are numerous within the HF.5 assemblage, the decrease in mean fork length is more likely associated with resource patch choices.

Based on the data presented, resource depression occurred at Mink Island during Stage II (Ocean Bay II, LM I). Mean fork lengths associated with stage II are significantly smaller than are their Stage IV (Thule/Koniag, UM I) counterparts. This pattern indicates that a combination of human harvesting pressure and climate change was responsible for patterning the fork length data. Resource depression during Stage II likely occurred when occupants exploited near-shore patches (located near sea mammal rookeries). Therefore, null hypotheses 7a (fork lengths do not differ significantly among temporal/cultural zones) and 7b (fork lengths do not differ significantly among climate zones) may be rejected. The data favors the acceptance of alternate hypotheses 7a (fork lengths differ significantly among temporal/cultural zones) and 7b (fork lengths differ significantly among climate zones).

Results: Resource Intensification and Patch Choice

The resource intensification hypothesis may be tested on the Mink Island fish bone assemblage by measuring change over time of taxonomic proportions, and evenness. An increase in the percentage of salmon found in an archaeological assemblage coupled with a decrease in evenness is indicative of intensified exploitation of salmon (Partlow, 2000). Additionally, skeletal element representation (e.g. the ratio of cranial to post-cranial skeletal elements) may also be used to indicate resource intensification (e.g. Butler and Chatters, 1994; Cannon, 1991, 1998; Matson and Coupland, 1995; Partlow, 2000).

Because taphonomic agents affect salmon skeletal elements differently based on BVD differences (Chapter 6), it is essential to complete taphonomic analysis before applying resource intensification models to the Mink Island assemblage. As discussed in Chapter 6, salmon abundance (%MAU) and BVD are not significantly correlated ($p>.05$) during any of the temporal/cultural zones, dense bones are not the most numerous. The high percentage of salmon vertebrae and basipterygia relative to the total NISP values is indicative of salmon storage (Cannon, 1991). Based on the taphonomic data, differential cultural processing (e.g. storage) was responsible for structuring the bulk of the Mink Island salmon bone assemblage.

By establishing that cultural processes (e.g. biostratinomic agents) were largely responsible for structuring the Mink Island salmon bone assemblage, it is possible to test the resource intensification hypothesis. Taxonomic proportions were measured using a salmon index [$\sum$ NISP Salmonidae / ($\sum$ NISP Salmonidae + $\sum$ NISP other fish taxa)]. Salmon index values range from 0-1: higher values demonstrate a greater reliance on salmon, and, are suggestive of resource intensification (Partlow, 2000). Additionally, because salmon were obtained from riverine patches along the Shelikof Strait coast and the other fish taxa were obtained from near-shore marine patches, the salmon index provides a means to test the patch choice model (Kopperl, 2003). However, because the patch choice index and the salmon index would be composed of the same values, the salmon index is the sole index presented. Inferences concerning patch choice are derived from the salmon index.

Taxonomic evenness, which measures the relative distribution of each taxon (Bobrosky and Ball, 1989), may be used to determine if an assemblage is dominated by one or more taxa.

Taxonomic evenness was measured using the Shannon Index of evenness ($e = H/\ln S$), which controls for sample size. Where H is the Shannon-Wiener heterogeneity index and S is taxonomic richness (Lyman, 2008: 195). Significant decreases in taxonomic evenness are interpreted to mean that foragers were relying on few resources and would be indicative of resource intensification (Cleland, 1966; Partlow, 2000).

Skeletal element representation, or the ratio of cranial to post-cranial skeletal elements may be used to infer processing for storage (Butler and Chatters, 1994; Hoffman *et al.*, 2000; Partlow, 2000). Salmon skeletal element representation was measured using MNE, MAU, and %MAU methods (see Chapter 2 for a complete description). Salmon skeletal elements were divided based on body regions, which include cranial, pectoral, pelvic, vertebral, and tail regions (e.g. Partlow, 2000). Higher abundance values associated with the tail, vertebral, pectoral, and pelvic regions is indicative of salmon storage (Butler and Chatters, 1994; Partlow, 2000). MNE, MAU, and %MAU values were calculated for the body regions. Because MNE values account for differential fragmentation (Lyman, 1994), they were used to represent abundance. MAU was calculated by determining the MNE value of a particular skeletal element and dividing it by the number of times the element is present within the body of a complete skeleton (Binford, 1978, 1984). %MAU values were obtained by dividing MAU values by the highest MAU value within an assemblage and then multiplying the quotient by 100.

If salmon specialization (i.e. resource intensification) occurred at Mink Island, the fish bone assemblage should be marked by an increase in salmon abundance compared to other taxa. Additionally, the assemblage should demonstrate a decrease in taxonomic evenness and markers for salmon storage should be present. Salmon index results are presented in Table 8.8. The ∑NISP values associated with the Upper Midden column sample (e.g. UM I, UM II, and UM III) are lower than those associated with the Lower Midden (e.g. LM I and LM II) because they were obtained using different recovery strategies (bulk sample 20x20 cm vs. excavation unit 16x16 m). The ∑NISP values associated with HF.5 are also reduced because of the recovery strategy (1x1m) and the sampling strategy employed (e.g. a random sample 2.5% vs. 100% analysis). However, because uneven ∑NISP distributions do not affect salmon index values, they are presented together in Table 8.8.

Table 8.8. Salmon index values associated with the model stages and the Mink Island temporal/cultural zones.

Model Stage	Temporal/ Cultural Zone	Salmon ∑NISP	Other Taxa ∑NISP	Salmon index
Stage IV	HF.5 (640-510 cal. BP)	2129	2890	0.42
	UM I (750-455 cal. BP)	37	179	0.17
	UM II (1000-750 cal. BP)	73	1141	0.06
Stage III	UM III (1600-1000 cal. BP)	137	1400	0.09
Stage II	LM I (5400-4100 cal. BP)	832	4701	0.18
Stage I	LM II (6700-5400 cal. BP)	259	1671	0.14

With the exception of the HF.5 collection, salmon comprised a small portion of the Mink Island fish bone assemblage (Table 8.8). Among the Lower Midden zones (LM II and LM I), salmon index values range between 0.14 and 0.18, which is low and suggests that salmon intensification did not occur during Stage I or Stage II. Salmon index values are even lower (0.09) during Stage III (UM III) as compared to the previous two stages. This pattern indicates that salmon are becoming less important during Stage III, which would not be expected if salmon intensification occurred. The decreasing salmon index trend continues during UM II; it lowers to 0.06 during the beginning of Stage IV (Thule/Koniag). This pattern suggests that salmon intensification was not present at Mink Island during this period. There is a moderate increase in the salmon index (0.17) associated with UM I, which is associated with Stage I (Thule/Koniag). Although this shift marks an increase in the importance of salmon at the site, 83% of the UM I assemblage is comprised of fish taxa other than salmon. Therefore, salmon intensification did not take place during this period. There is, however, an increase in the HF.5 (Stage IV, Thule/Koniag) salmon index (0.42). Slightly less than half of the fish bone sample analyzed here were salmon, which indicates that salmon were more important during this period, however, the percentage is not high enough to indicate the presence of salmon intensification.

The same salmon index data may be used to test the patch choice model (Kopperl, 2003). Riverine patches were not extensively exploited until Stage IV (Thule/Koniag-HF.5 assemblage). However, because other fish taxa (e.g. marine fishes) comprise ca. 52% of the

HF.5 assemblage, the Mink Island occupants were still exploiting marine patches during this period. Therefore, although salmon became more important during this period, the exploitation of riverine patches (using nets and weirs) occurred on a seasonal basis (e.g. late spring and summer). The Mink Island occupants exploited the marine patches, some of which were centrally located (e.g. Mink Island beaches), during the remaining months of the year. As small flatfishes, sculpins, and cods were available from nearshore locations (using single hooks) on Mink Island year-round, they provided fresh sources of protein during lean months (Crowell *et al.*, 2003).

Taxonomic evenness was measured using the Shannon Index of evenness ($e = H/\ln S$), which controls for sample size. The Shannon index of evenness is calculated by dividing the Shannon-Wiener heterogeneity index by the log (ln) of NTAXA (taxonomic richness). The resultant values should range between 0 and 1, with higher values signifying an even fauna (Lyman, 2008: 195). Significant decreases in taxonomic evenness would suggest that foragers were relying on a select few resources (Cleland, 1966; Partlow, 2000). The evenness data may be used in conjunction with the salmon index and skeletal element representation data to infer resource intensification at Mink Island.

The creation of the Shannon Index of evenness equation requires that the NTAXA and Shannon-Wiener heterogeneity values are known. NTAXA is a measure of taxonomic richness at one specific level (e.g. family, genus, species, etc.). NTAXA values are calculated by counting the number of taxa present within an assemblage (Lyman, 2008). The Shannon-Wiener index of heterogeneity is a measure of the proportion, or importance of each taxon within an assemblage. The Shannon-Wiener index of heterogeneity equation is as follows: $H = -\sum P_i(\ln P_i)$. Where p_i is the proportion (p) of taxon *i* in an assemblage. The proportion is then multiplied by the natural log (ln) of that proportion. The sums of the taxa are converted from a negative value to a positive value by placing a negative sign (-) in front of the sum ($\sum$) sign (Lyman, 2008: 192). The Shannon-Wiener index of heterogeneity values typically range between 1.5 and 3.5. Lower values indicate a more homogeneous sample (dominated by one or two taxa), whereas higher values indicate a more heterogeneous sample (representing many different taxa) (Lyman, 2008).

Taxonomic richness values (NTAXA) are presented with $\sum$NISP values in Table 8.9. Taxonomic richness decreases over time at Mink Island. The occupants of Stages I, II, and III (LM

II, LM I, and UM III) exploited a diverse number of fish taxa, whereas, the number of taxa exploited by the occupants of stage IV (UM II and UM I) is lower. The HF.5 assemblage (Stage IV, Thule/Koniag) is represented by a notable increase in taxonomic richness. Whether this pattern is related to spatially distinct dumping episodes of fish remains or an actual increase in the number of taxa exploited is presently unknown. Additional excavation aimed at understanding the spatial distribution of faunal resources at Mink Island is needed to understand this phenomenon.

Table 8.9. Total NISP and NTAXA values associated with the Mink Island temporal/cultural zones.

Temporal/Cultural Zone	∑NISP	NTAXA
HF 5 (640-510 cal. BP)	4413	16
UM I (750-455 cal. BP)	164	7
UM II (1000-750 cal. BP)	992	12
UM III (1600-1000 cal. BP)	1217	18
LM I (5400-4100 cal. BP)	4241	21
LM II (6700-5400 cal. BP)	1452	20

Individual Shannon-Wiener heterogeneity index values are presented in Appendix J. The genus-level taxonomic identifications that comprise the NTAXA values are presented in the first column of each table. The Shannon-wiener heterogeneity index values for the assemblages are presented in the bottom right corner of each figure. All of the heterogeneity values are combined in Table 8.10. The heterogeneity index value associated with Stage I of the model (LM II) is 2.23, which suggests that the assemblage is relatively heterogeneous. The LM II assemblage is comprised of a wide assortment of taxa (especially members of the family pleuronectidae=62%), which suggests that the occupants employed a generalized procurement strategy. Salmon comprise 9% of the LM II assemblage. The heterogeneity index value associated with Stage II of the model (LM I) is 1.54, which indicates that the assemblage is homogeneous. Pacific cod comprise almost 56% of the LM I assemblage, whereas salmon compose a little over 12%. The UM III assemblage, which belongs to stage III of the model, has a

heterogeneity index of 1.47, which is also homogeneous (Table 8.10). Pacific cod compose nearly 63% of the UM III assemblage, whereas salmon are 11%. The heterogeneity index for UM II, which belongs to stage IV, is 1.09, which indicates that the assemblage is homogeneous (Table 8.10). Pacific cod comprise 75% of the UM II assemblage, whereas salmon only compose 7%. The heterogeneity index for UM I, which also belongs to Stage IV, is 1.60 (Table 8.10); and is substantially more heterogeneous as compared to the previous temporal/cultural zone (UM II). UMI is dominated by Pacific cod, and salmon compose 7% of the assemblage. Lastly, the heterogeneity index for HF.5 is 1.42, which is more homogeneous as compared to the UM I assemblage (Table 8.10). Salmon compose 48% of the assemblage, and saffron cod, Pacific cod, Pacific herring, and Irish lords together comprise 49% of the assemblage. The other 11 taxa comprise the remaining 3% of the assemblage.

When examined together, the Shannon-Wiener heterogeneity index indicates that the LM II (Ocean Bay I, Stage I) assemblage is more heterogeneous than any other period. This pattern suggests that the occupants employed a generalized subsistence pattern in which they exploited a wide variety of fish taxa. There is a sharp decrease in heterogeneity associated with LM I (Ocean Bay II, Stage II), during which time the occupants began to focus on Pacific cod, however Irish lords and salmon are also abundant. The same general trend continues into the UM III (Norton/Kachemak, Stage III). There is a large decrease in heterogeneity associated with UM II (Thule/Koniag, Stage IV). The UM II assemblage is dominated by Pacific cod; however, Irish lords and salmon are also numerous. The UM I assemblage demonstrates an increase in heterogeneity, and displays a mixed strategy where Irish lords and salmon are most numerous; herring and Pacific cod are also abundant. Finally, the HF.5 assemblage is dominated by salmon, which represents the only period where salmon comprise a substantial portion of the assemblage.

Table 8.10. Shannon-Wiener Index of Heterogeneity for the Mink Island temporal/cultural zones

Temporal/Cultural Zone	Shannon-Wiener Index of Heterogeneity $H=-\sum P_i(\ln P_i)$
HF.5 (640-510 cal. BP)	1.42
UM I (750-455 cal. BP)	1.60
UM II (1000-750 cal. BP)	1.09
UM III (1600-1000 cal. BP)	1.47
LM I (5400-4100 cal. BP)	1.54
LM II (6700-5400 cal. BP)	2.23

The Shannon index of evenness values for the Mink Island temporal/cultural zones are presented in Table 8.11. NTAXA values and Shannon-Wiener index of heterogeneity values were used to compose evenness values. As stated earlier, evenness index values range from 0-1, the higher the value the more even the assemblage. The highest evenness value was obtained from the LM II (Ocean Bay I, Stage I) assemblage (0.74), which suggests that the occupants relied on a wide variety of fish taxa. The evenness value associated with LM I (Ocean Bay II, Stage II) is 0.50, which indicates that the number of fish taxa exploited decreased during this period. This pattern continues within Stage III (UM III, Kachemak/Norton), which has an evenness value of 0.51 The assemblage becomes less even 0.44 even within the ensuing assemblage UM II (Thule/Koniag, Stage IV). The pattern suggests that the occupants relied more heavily on a select few taxa (especially Pacific cod). There is a marked increase in evenness (0.68) associated with the UM I assemblage (Thule/Koniag, Stage IV). The assemblage mixed with Irish lords, Pacific cod, and salmon composing the bulk of the assemblage. Finally, the evenness value is reduced again in the HF.5 (Thule/Koniag, Stage IV) assemblage (0.51). The HF.5 assemblage is comprised of a mixture of salmon, Pacific cod, saffron cod, Pacific herring, and Irish lord specimens.

Table 8.11. Shannon Index of Evenness values associated with the Mink Island temporal/cultural zones.

Temporal/Cultural Zone	Shannon Index of Evenness $e = H/\ln S$
HF 5 (640-510 cal. BP)	0.51
UM I (750-455 cal. BP)	0.68
UM II (1000-750 cal. BP)	0.44
UM III (1600-1000 cal. BP)	0.51
LM I (5400-4100 cal. BP)	0.50
LM II (6700-5400 cal. BP)	0.74

Salmon index, Shannon-Wiener index of heterogeneity, and the Shannon index of evenness values are presented together in Figure 8.1. HF.5 and UM I values are from the same temporal/cultural zone but have been separated because they were recovered from two distinct loci. By presenting the three indices together, it is possible to track resource intensification over time using three different proxy indicators. Lower heterogeneity and evenness values in conjunction with higher salmon index values are indicative of resource intensification (Partlow, 2000). As Figure 8.1 illustrates, the index values associated with LM II are opposite from expected for resource intensification. The occupants of Stage I, practiced a generalized foraging pattern that was comprised of several taxa, especially members of the family Pleuronectidae (flatfishes). Heterogeneity and evenness were substantially reduced and the salmon index increased during the shift to stage II (LM I). This pattern represents the beginning reliance on Pacific cod that continues throughout the remaining periods at Mink Island. The same general pattern is visible in the UM III assemblage, which represents the shift to Stage III. Pacific cod remains dominate other taxa during this period. The shift to Stage IV, associated with the UM II assemblage is marked by decreased heterogeneity and evenness; Pacific cod comprise the bulk of this assemblage. The marked increase in heterogeneity and evenness associated with UM I (Stage IV) is indicative of a reliance on a variety of taxa (salmon, Irish lords, herring, and Pacific cod). The increase in the salmon index, demonstrates that salmon are becoming more important to the occupants. Finally, the decrease in heterogeneity and the increase in the

salmon index associated with HF.5 (Thule/Koniag, Stage IV) mark a greater reliance on salmon, however it does not indicate resource intensification is present at Mink Island.

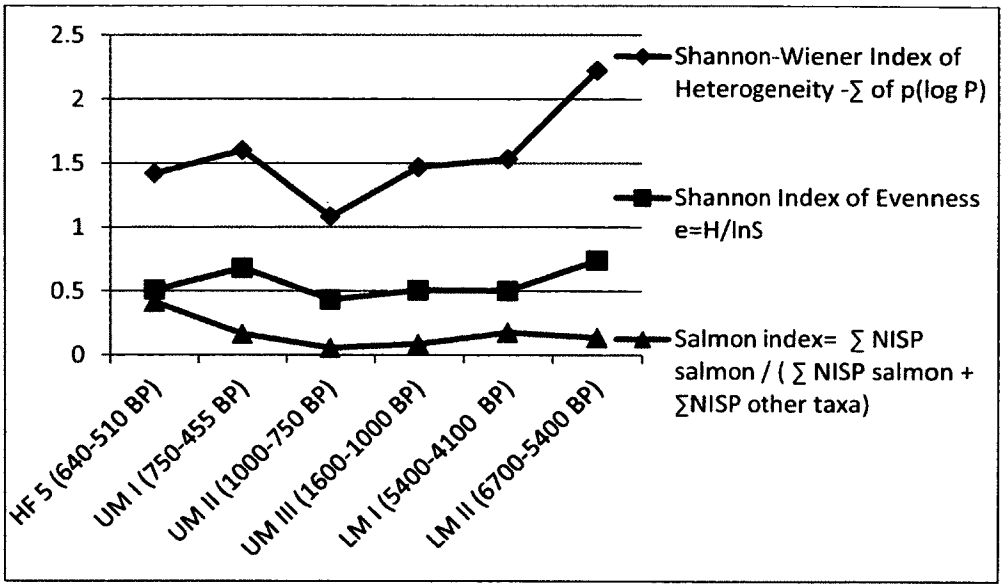


Figure 8.5. Shannon-Wiener Index of Heterogeneity, Shannon Index of Evenness, and Salmon Index for the Mink Island temporal/cultural zones. Radiocarbon age ranges are calibrated (2-sigma).

Salmon Storage

After the differential effects of diagenic agents have been ruled out as the primary assemblage-structuring agent, it is possible to use assemblage composition to infer processing of salmon for storage. As I stated in Chapter 6, BVD differences were not significantly correlated with salmon abundance (%MAU) ($p > .05$), which indicates that humans (e.g. biostratinomic agents) were primarily responsible for structuring the salmon bone assemblage at Mink Island. Evidence for processing of salmon for storage, therefore, may be obtained by measuring skeletal element representation (Partlow, 2000). Salmon skeletal element representation was measured using MNE, MAU, and %MAU methods. Following the work of Partlow (2000), the assemblage

was divided into five body regions: cranial, pectoral, pelvic, vertebral and tail. The skeletal elements in each body region are listed in Figure 8.6.

Cranial: Articular, alisphenoid, basioccipital, ceratohyal, dentary, ectopterygoid, epihyal, epiotic, ethmoid, exoccipital, frontal, hyomandibular, interopercular, lachrymal, maxilla, mesopterygoid, metapterygoid, nasal, opercle, opisthotic, orbitosphenoid, otolith, palatine, parasphenoid, parietal, prefrontal, premaxilla, preopercle, prootic, pterotic, quadrate, sphenotic, subopercle, supraoccipital, symplectic, urohyal.
Pectoral: Cleithrum, coracoid, mesocoracoid, postcleithrum, posttemporal, radial, scapula, supracleithrum.
Pelvic: Basipterygium, interhaemal spine.
Vertebral: Vertebra.
Tail: Caudal bony plate, epural, hypural, ultimate vertebra.

Figure 8.6. Pacific salmon skeletal elements divided by body region.

MNE, MAU, and %MAU values for the body regions divided by temporal/cultural zone are presented in Tables 8.12-8.17. The LM II (Ocean Bay I, Stage I) assemblage is composed entirely of vertebrae, and therefore, the pattern indicates that salmon were processed for storage (Table 8.12). However, because the entire assemblage is represented by three individuals (MAU=2.16), the data indicate that salmon did not compose a large portion of the diet during this period. The LM I (Ocean Bay II, Stage II) assemblage is composed mostly of vertebrae, however two other skeletal elements are present within the assemblage (Table 8.13). Because only one skeletal element belonging to the cranial body region was recovered from this assemblage, the pattern is consistent with salmon processed for storage. Although salmon skeletal elements are more numerous than the previous assemblage, the entire LM I assemblage is comprised of 9 individuals (MAU=8.89). Therefore, salmon did not comprise a large portion of the diet during this period. There is a distinct shift associated with the UM III (Norton/

Kachemak, Stage III) assemblage (Table 8.14). Skeletal element representation is spread almost evenly across the body regions. Cranial skeletal elements have a %MAU value of 67, consistent with the deposition of whole specimens. Therefore, salmon were not processed for storage during this period. The low abundance of salmon (MAU=3) indicates that occupants focused on other taxa during this period. Cranial skeletal elements are absent from the UM II (Thule/Koniag, Stage IV) assemblage. Therefore, salmon were processed for storage. Salmon did not comprise a large portion of the diet based on the low abundance value (MAU=1.02). Cranial skeletal elements are also absent from the UM I (Thule/Koniag, Stage IV) assemblage, which suggests that the salmon were processed for storage (Table 8.16). The low abundance value (MAU=2) suggests that salmon did not compose a large portion of the assemblage. Finally, the HF.5 assemblage (Thule/Koniag, Stage IV) is almost entirely composed of non-cranial skeletal elements, and demonstrates that salmon were processed for storage (Table 8.17). The high abundance value (MAU=36), estimates at least 36 individuals represented in the assemblage. The increase in abundance coupled with the scarcity of cranial skeletal elements is strongly indicative of storage.

The skeletal element representation data suggests that during all periods except UM III (Norton/Kachemak, Stage III), there is evidence of processing salmon for storage. However, because salmon abundance is low for all periods, resource intensification does not appear to have taken place at Mink Island. MNE and MAU values associated with HF.5 increase compared to those from other temporal/cultural zones; however, it may not be enough to demonstrate resource intensification on salmon.

Table 8.12. MNE, MAU, and %MAU values of Pacific cod body regions associated with the LM II (6700-5400 cal. BP) assemblage.

LM II (6700-5400 cal. BP)			
Body Region	**MNE**	**MAU**	**%MAU**
Cranial	0	0	0
Pectoral	0	0	0
Pelvic	0	0	0
Vertebral	133	2.16	100
Tail	0	0	0

Table 8.13. MNE, MAU, and %MAU values of Pacific cod body regions associated with the LM I (5400-4100 cal. BP) assemblage.

LM I (5400-4100 cal. BP)			
Body Region	**MNE**	**MAU**	**%MAU**
Cranial	1	0.5	6
Pectoral	3	1	11
Pelvic	0	0	0
Vertebral	547	8.89	100
Tail	1	1	11

Table 8.14. MNE, MAU, and %MAU values of Pacific cod body regions associated with the UM III (1600-1000 cal. BP) assemblage.

UM III (1600-1000 cal. BP)			
Body Region	**MNE**	**MAU**	**%MAU**
Cranial	5	2	67
Pectoral	11	1.5	50
Pelvic	6	3	100
Vertebral	103	1.67	56
Tail	3	2	67

Table 8.15. MNE, MAU, and %MAU values of Pacific cod body regions associated with the UM II (1000-750 cal. BP) assemblage.

UM II (1000-750 cal. BP)			
Body Region	**MNE**	**MAU**	**%MAU**
Cranial	0	0	0
Pectoral	8	1	98
Pelvic	1	0.5	49
Vertebral	63	1.02	100
Tail	1	1	98

Table 8.16. MNE, MAU, and %MAU values of Pacific cod body regions associated with the UM I (750-455 cal. BP) assemblage.

UM I (750-455 cal. BP)			
Body Region	**MNE**	**MAU**	**%MAU**
Cranial	0	0	0
Pectoral	20	2	100
Pelvic	2	1	50
Vertebral	11	0.18	9
Tail	4	1	50

Table 8.17. MNE, MAU, and %MAU values of Pacific cod body regions associated with the HF.5 (640-510 cal. BP) assemblage.

HF.5 (640-510 cal. BP)			
Body Region	**MNE**	**MAU**	**%MAU**
Cranial	7	1	3
Pectoral	102	11	31
Pelvic	72	36	100
Vertebral	1914	31.12	86
Tail	19	19	53

The combined taxonomic proportion, heterogeneity, and evenness data demonstrates that salmon intensification did not occur at Mink Island during any period. There is a large increase in salmon abundance and an associated decrease in heterogeneity and evenness values associated with the HF.5 assemblage, which dates between 640-510 cal. BP (Hilton, 2002). However, this increase is not large enough to suggest resource intensification focused on salmon. Throughout the previous stages, the occupants of Mink Island procured diverse taxa, composed mostly of Pacific cod, Irish lords, salmon, and small flatfishes.

The salmon index data suggests that riverine patches along the Shelikof Strait coast were not extensively exploited until Stage IV (Thule/Koniag). However, the Mink Island occupants were still exploiting marine patches during this period. Therefore, the data indicates that the riverine patches were exploited on a seasonal basis (e.g. late spring and summer). Marine patches were exploited during the remaining months. Small flatfishes, sculpins, and cods caught nearshore by hook and line year-round, provided fresh sources of protein during lean months (Crowell *et al.*, 2003).

When the salmon index, heterogeneity, and evenness data are combined with the taphonomic evidence of salmon processing (see Chapter 6), it is clear that humans (e.g. biostratinomic agents) were primarily responsible for structuring the salmon assemblage during all periods. More research is needed to explore possible differences in spatial organization at Mink Island. Although the evidence suggests that salmon became more important during the latter part of the Thule/Koniag period at HF.5, additional archaeological excavations may eliminate confusion concerning the degree to which salmon were exploited. If the Upper Midden column sample were the sole locus of exploration during Stage IV, no evidence of increased salmon usage would be present. Because the Upper Midden column sample and the HF.5 assemblages are both comprised of midden dump episodes, the distinction is not because they are different types of deposits (e.g. midden vs. house floor). The discrepancy between the two loci represents one of several possibilities: 1) The occupants may have deposited salmon remains in different places across the site during this period, 2) The fish remains deposited in HF.5 were deposited after those that were deposited in UM I, 3) The two assemblages were deposited during different seasons, or 4) the two assemblages represent distinct cultural

activities. This question may only be answered by analyzing additional assemblages associated with the most recent occupations at Mink Island with multiple radiocarbon dates.

Changing Lifeways along the Shelikof Strait Coast: Inferences from Ethnographic and Archaeological Sources

The fish bones recovered from the Mink Island site provide a means to track changing interactions among humans and fishes along the Shelikof Strait coast. The data indicate that foraging strategies varied over time in response to population pressure, mobility patterns, climatic conditions, labor organization, and technological innovations (Fitzhugh, 1996). In the following paragraphs, the fishbone data is used with data derived from ethnographic and archaeological sources to present a more robust view of changing lifeways among prehistoric peoples at Mink Island.

The distribution, diversity, density, and accessibility of biological resources directly affect the location and type of human habitation on the coast (Crowell and Mann, 1996). Because biological resources varied at many scales (seasonal, annual, centennial, and millennial), human habitation types, and locations also varied at the same scales. By examining archaeological site locations in relation to biological resource distributions, it may be possible to identify the nature of human use of a location (site-type) (Crowell *et al.*, 2003; Crowell and Mann, 1996).

Biological resources are unevenly distributed along the Shelikof Strait coast; they tend to cluster in the diverse habitats found along the convoluted coastline between Dakavak and Hallo Bays (Crowell *et al.*, 2003). Archaeological sites tend to cluster where the biological resources concentrate; therefore, they are more numerous along a convoluted coastline (Figure 8.3) (Crowell and Mann, 1996; Crowell *et al.*, 2003). Were biological resources cluster, occupants tend to aggregate in village locations. Where biological resources are widely dispersed, occupants tend to spread to acquire diverse resources (Erlandson *et al.*, 1992).

Biological resource density (the number of separate resources locales) is also typically higher in areas surrounding the convoluted coastline between Dakavak and Hallo Bays (Crowell *et al.*, 2003). Amalik, Kinak, Kuliak, and Kaflia Bays support especially dense resource

concentrations; and archaeological sites tend to cluster in these locations (Figure 8.7) (Crowell *et al.*, 2003). Biological resource density is lower between Cape Douglas and the north end of Hallo Bay and the area surrounding Katmai Bay, and, archaeological site numbers are also lower (Figure 8.7) (Crowell *et al.*, 2003).

The accessibility of biological resources was another factor in determining the location and type of human settlements along the Shelikof Strait coast (Erlandson *et al.*, 1992). Inner bays along the convoluted coastline between Dakavak and Hallo Bays provided shelter from wind and waves that battered the open coast and provided areas to land and launch small boats (Crowell *et al.*, 2003; Erlandson *et al.*, 1992; Fitzhugh, 1996, 2002). Archaeological sites in these protected areas tend to be logistical camps associated with procurement of seasonally available resources (salmon) and terrestrial animals (caribou). Outer, more exposed beaches at the mouth of bays (including small islands like Mink Island) within the convoluted coastline provided access to diverse biological resources, abundant driftwood concentrations, and provided unobstructed views of the surrounding environment (Crowell *et al.*, 1996; Hilton, 2002). Archaeological sites in these more exposed outer bays tend to be winter villages, near abundant shellfish and fish populations that are available year-round (Crowell *et al.*, 2003).

Coupled with uneven geographic distribution, biological resources present along the Shelikof Strait experienced uneven temporal distribution. These biological resources varied at seasonal, annual, centennial, and millennial scales (Crowell *et al.*, 2003; Erlandson *et al.*, 1992; Fitzhugh, 2003; Haggerty *et al.*, 1991). Because humans are invariably linked with these varying biological resources; habitation locations, and site-types varied at the same scales (Crowell *et al.*, 2003). Ethnohistoric Kodiak Alutiiq annual seasonal round data, collected by Crowell *et al.* (2003), is used here as a proxy for the prehistoric Alaska Peninsula Alutiiq (Sugpiaq) because direct ethnohistoric data on the peninsula is lacking (Figure 8.8). From October until March, the coastal Kodiak Alutiiq congregated into well-established winter villages where they procured relatively few biological resources (Crowell *et al.*, 2003). These winter villages tended to be along more exposed beaches at the mouth of bays (including small islands). The diet during these relatively unproductive winter months consisted mostly of dried salmon, berries, seal oil, and other stored foods. Foul weather often precluded travel to distant locations and winter villages were typically near abundant, easily accessible resources (shellfish, marine fish, sea

mammals, and birds). Close proximity to productive shellfish beds may have been especially important because they provided fresh food during the lean months (Crowell *et al.*, 2003; Erlandson *et al.*, 1992). Pacific cod and other marine fishes accessible from shore (sculpins, flatfishes, etc.) were also important food sources during these lean months (Davydov, 1977). Northern fur seals became available offshore of Kodiak Island from February through April (Calkin, 1986; Merck, 1980; Sauer, 1802). Bird eggs were available in the area during February and March (Sauer, 1802).

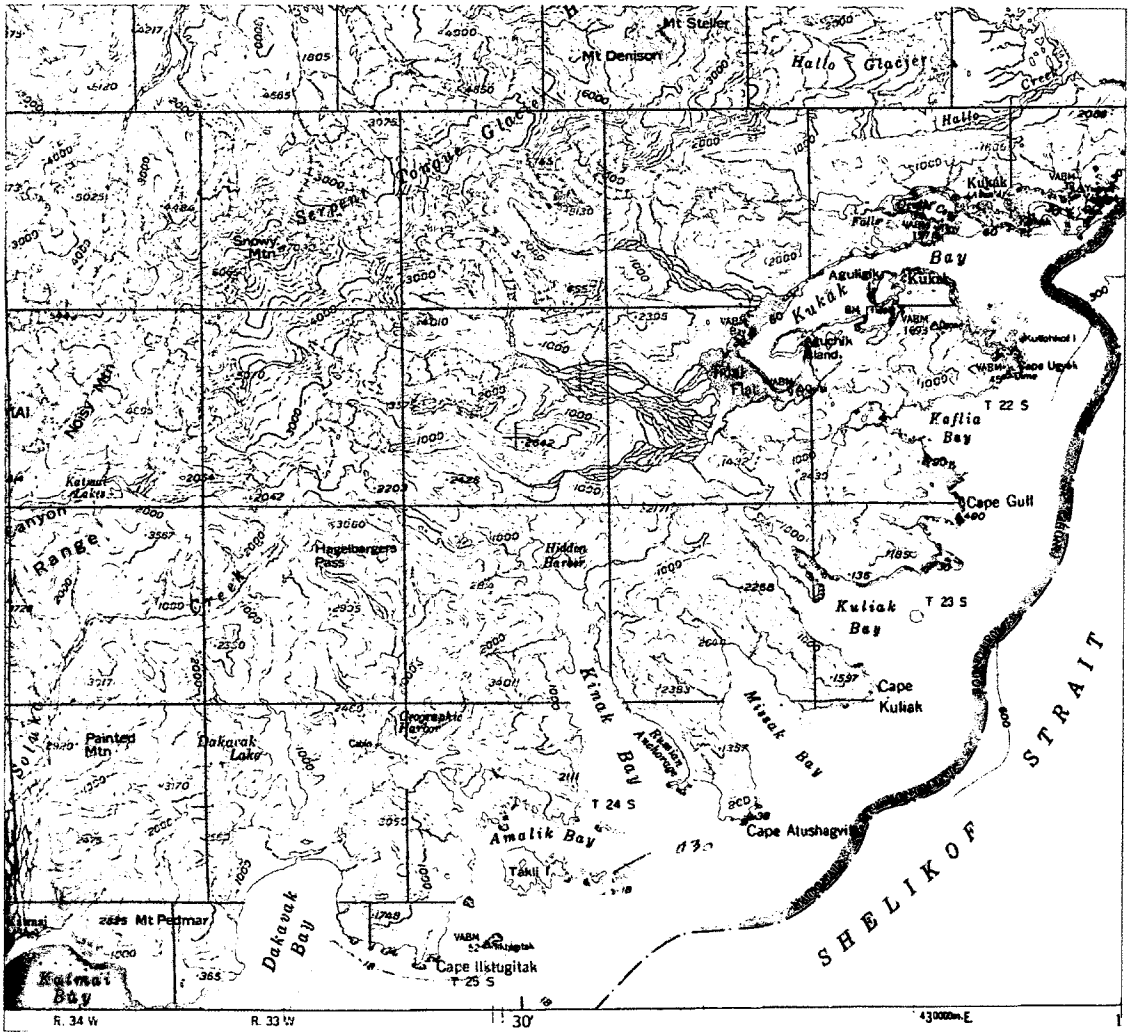


Figure 8.7. Topographic map of the coastal region between Dakavak and Hallo Bays. Mt. Katmai Quadrangle.

From April through September the Kodiak Alutiiq were more widely dispersed because biological resources were more widely dispersed (Black, 1977; Davydov, 1977; Lisianskii, 1814; Merck, 1980; Sauer, 1802). The Alutiiq peoples focused on procuring seasonally available and seasonally congregated resources such as whales, salmon, herring, seabirds, and mammals during this period (Erlandson *et al.*, 1992). Small, logistical camps were established near high-yield procurement localities such as salmon streams, sea bird colonies, and sea mammal haul-outs. Individuals or small task groups would stay at these logistical camps for days or weeks accumulating stores of dried meat, fish, and other foods. Afterwards, the accumulated dried food would be transported back to the main village area by boat. Because many villages were in ecologically rich zones, many resource procurement efforts were staged entirely from winter villages, where many of the residents lived year-round (Clark, 1987; Crowell *et al.*, 2003; Haggarty *et al.*, 1991).

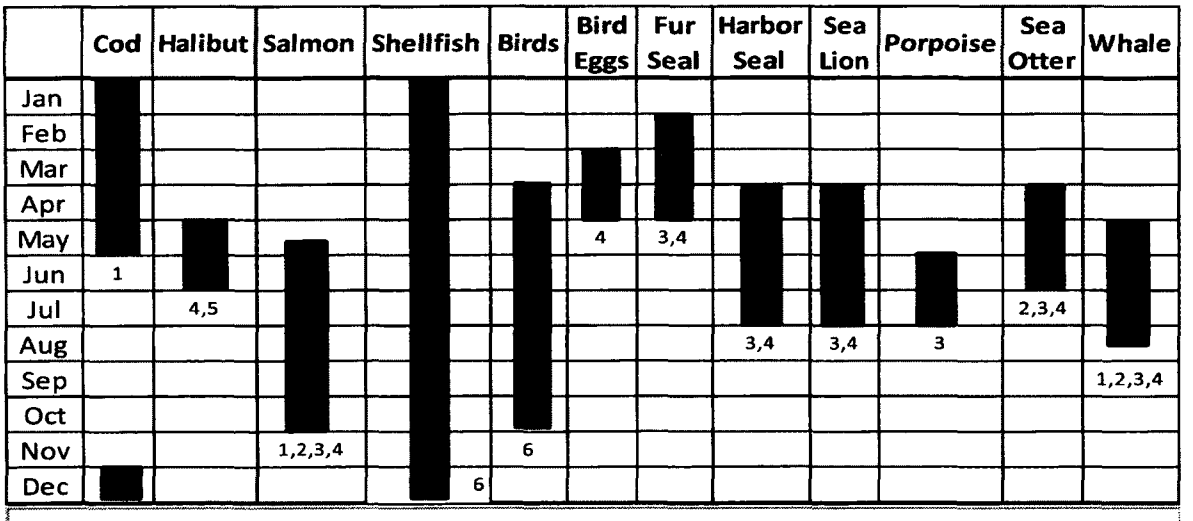


Figure 8.8. Ethnohistorically reconstructed Alutiiq seasonal round for Kodiak Island, circa 1790-1805 A.D. Based on Crowell *et al.*, 2003, Figure 3.

The Mink Island site is near the mouth of Amalik Bay, which is found on the convoluted coastline between Hallo and Dakavak Bays (Figure 8.7). Results of the geospatial analysis completed by Crowell *et al.* (2003) demonstrate that Amalik Bay has the highest modern biological resource density (24 resources) of any of the bays along the Shelikof Strait coast. Amalik bay is especially rich in sea mammal (harbor seal, Steller sea lion, sea otter, and harbor porpoise) resources; however, many fish (pink salmon, chum salmon, Pacific herring, Pacific halibut, and Pacific cod), birds (seabirds and waterfowl), and shellfish resources are also present (Crowell *et al.*, 2003).

Based on the available archaeological data (site location and features), the Mink Island site may have been used differently by its prehistoric occupants throughout the stages (I-IV). The level of human occupation likely ranged from occasional use as a logistical camp (Stages I and II) to long-term use as a winter-village (Stage IV). Periodic occupational hiatuses (4,050 to 2,000 cal. BP) may have been caused by abrupt changes in environmental conditions, sea level changes, or volcanic eruptions, and associated ash fall (Crowell *et al.*, 2003).

The initial occupation during the Paleoarctic tradition (not part of the four-stage model) may represent a logistical camp focused on procuring sea mammals (Steller sea lions). While no faunal materials were recovered from this period at Mink Island (likely because of destruction by taphonomic agents), immature sea lion bones are found within the later lithostratigraphic levels (Schaaf, 2009). Evidence for human habitation at the site during this period is limited to a small, ochre-stained, basin-shaped living surface (Schaaf, 2009). Other architectural details associated with the house floor are two perpendicular berms situated along the living surface and an ochre-stained storage pit below the floor (Schaaf, 2009). No other structural details are currently available because the house feature was not fully excavated and erosion has blurred the lines of the house (Schaaf, 2009). While there is no supporting evidence within the artifact assemblage, these people undeniably used watercraft to travel, access fishing grounds, and to hunt sea mammals (Schaaf, 2009).

Based on lithostratigraphic data, a stormy period followed the initial occupation at Mink Island. The next human occupation closely followed a volcanic eruption that deposited a 10 cm (4 in) thick layer of tephra ca. 6550 cal. BP (Schaaf, 2009). These people (Stage I, Ocean Bay I) were largely after sea mammals (Steller sea lions) (Figure 8.9); however, whale bone clam

digging tools demonstrate that they also procured shellfish, and grooved pumice net floats, and net sinkers support the interpretation that they fished with nets (Schaaf, 2009). No house floors dating to this period are identified at Mink Island. Additional excavation at the site is needed to determine if the dearth of house features during this period is an artifact of the sampling design or of human occupation strategies. If house features are truly absent during this period, the occupation during the initial phase of the Ocean Bay tradition may have been limited to a logistical camp focused on Steller sea lion procurement.

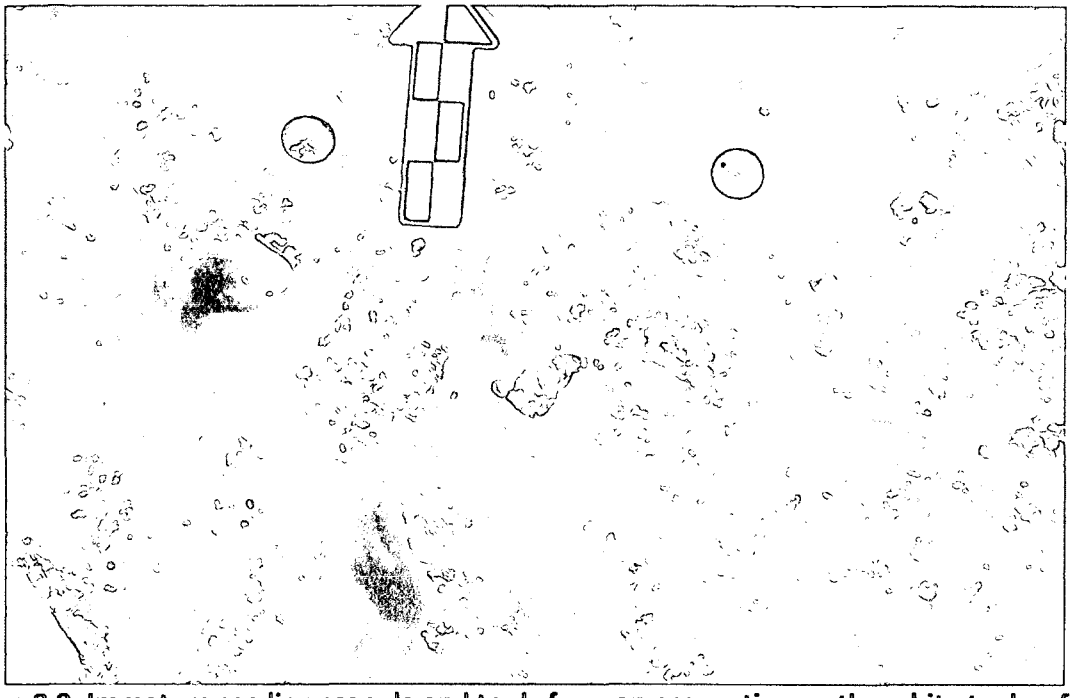


Figure 8.9. Immature sea lion scapula and tools from an occupation on the white tephra from a volcanic eruption, 6500 cal. BP. Photo from Schaaf (2008: Figure 6, pp. 37).

There is evidence that people occupied the Mink Island site approximately 5950 cal. BP during the winter months in a substantial house (Schaaf, 2009). Thick, laminated floor sediments support the interpretation that the house was occupied for many years. This type of coastal winter house is rare in Alaska during the mid-Holocene (Stage I) (Schaaf, 2009). Following the winter occupation at the Mink Island site, the region experienced a brief cold period. The ensuing occupation (Stage I, Ocean Bay I) at the site was relatively light until

ca.5350 cal. BP, when a small, temporary shelter was used (Figure 8.10) (Schaaf, 2009). The small shelter consisted of an oval, shallow, ochre-covered floor that was shielded by an ochre-covered hide supported by poles (Schaaf, 2009). During this period, the Mink Island site was likely used as a logistical base camp. Lying on top of the temporary shelter is a 90 cm (36-in) thick deposit of mixed cultural materials that ranged from 5350 to 4050 cal. BP (mixed Stage I and Stage II) (Schaaf, 2009). The cultural materials from this deposit, which include occupation surfaces, reflect uninterrupted site-use that was deposited rapidly (Schaaf, 2009). The absence of substantial winter houses (during Stage II) demonstrates that the Mink Island site served as a logistical base camp during this period.

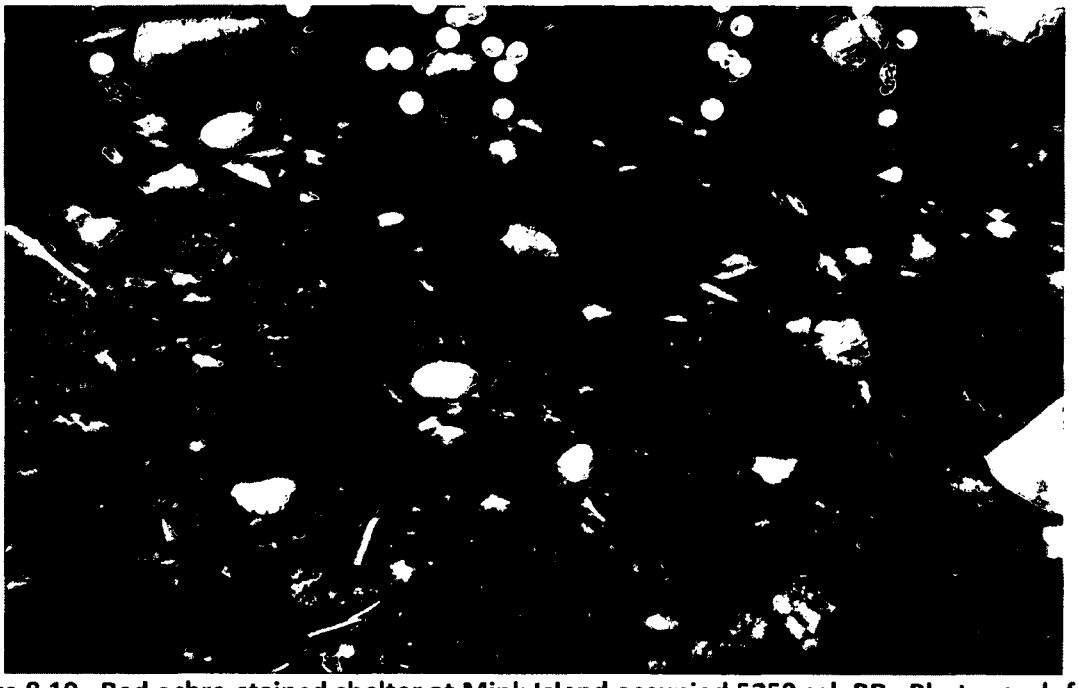


Figure 8.10. Red ochre-stained shelter at Mink Island occupied 5350 cal. BP. Photograph from Schaaf (2008: Figure 7, pp. 38).

At approximately 4050 cal. BP, the Mink Island site was apparently abandoned, for ca. 2000 years (Schaaf, 2009). By ca. 2000 cal. BP, the site was re-occupied by individuals for ca. 1500 years (Stage III, Norton/Kachemak; Stage IV, Thule/Koniag) who deposited vast quantities

of shells and bones in a midden on top of the earlier components (Paleoarctic and Ocean Bay traditions) (Figure 8.11) (Schaaf, 2009). The Mink Island occupants of this period (Stage IV) resided in a small village, probably a winter village (e.g. Crowell, 2003), and procured a wide variety of intertidal resources, sea mammals (including whales), birds (sea birds and waterfowl), and fishes (mostly Pacific cod, sculpins, salmon, and flatfishes) (Schaaf, 2009).

Figure 8.11. Extensive shell and bone accumulation associated with Upper Midden (Stages III and IV). Mike Hilton is shown here preparing a sediment peel from this shell midden. Photo from Schaaf (2008: Figure 8, pp. 38).

Based on the data presented here, the Mink Island occupants followed some, but not all of the model predictions. Although, there is evidence for resource depression during Stage II, there is no evidence of salmon intensification during Stage III or IV. However, salmon does

become more important during Stage IV (HF.5, 640-510 cal. BP), other marine fishes (e.g. Pacific cod, saffron cod, sculpins, and Pacific herring) are also abundant within the assemblage. Therefore, this pattern indicates that prehistoric occupants exploited seasonally available resources while residing on Mink Island during Stages II-IV. They procured salmon from rivers along the Shelikof Strait coast during the spring and summer (using nets and weirs), and ate dried salmon during the winter months. They also captured marine fishes (with hook and line) from nearshore patches during the remaining months. The distance they traveled from the Mink Island site largely depended on climatic conditions. However, because many of the fish taxa were available from Mink Island beaches, nearshore marine fish comprised a substantial part of the diet during Stage III and IV. The only stage in which fish were not a major food source at Mink Island was during Stage I (Ocean Bay I, LM II). Large-bodied, high-ranking sea mammals (mostly Stellar sea lions) were the primary focus during this period.

Regional Connections

To determine where the Mink Island fish bone data fits within the regional pattern, the Lower Midden and Upper Midden abundance data (NISP) are compared to the abundance data from Rice Ridge (KOD-363) and the Settlement Point (AFG-015) sites (Kodiak Archipelago) (Figure 8.12). The Rice Ridge data was obtained from Kopperl (2003: pp. 117, Table 4.1 and pp. 167, Table 5.1), and the Settlement Point data was attained from Partlow (2000: pp. 74, Table 4.01; pp. 145, Table 7.01). For consistency, the Rice Ridge, Settlement Point, and Mink Island fish fauna data compared here were recovered solely from midden contexts. The Rice Ridge data (midden levels A and C) are roughly contemporaneous with the LM I (5400-4100 cal. BP) and LM II (6700-5400 cal. BP) assemblages and the Settlement Point data (midden levels 1, 2, 2D, and 2G) are roughly contemporaneous with the UM I (750-455 cal. BP) and HF.5 assemblages (640-510 cal. BP). Because fish bone data that is directly comparable to the Mink Island UM II and UM III assemblages (e.g. from midden contexts that date between 1600-750 cal. BP) are not readily available, they have been omitted from this discussion.

Before comparing and contrasting the fish bone abundance data from the three sites, it is necessary to discuss how mesh sieve size differences (0.64 cm vs. 0.32 cm) affect assemblage

composition (e.g. heterogeneity and evenness). The Rice Ridge site was sieved through 0.64 cm (1/4 in) mesh (Kopperl, 2003), whereas the Settlement Point and Mink Island sites were sieved through 0.32 cm (1/8 in) mesh (Hilton, 2002; Partlow, 2000). Without first establishing the effects of differing screen sizes on the fish bone assemblages, the results may be skewed in favor of larger skeletal elements from larger fish taxa (Partlow, 2000, 2006).

The effects of using 0.64 cm (1/4 in) vs. 0.32 cm (1/8 in) sieve sizes are established on two Mink Island assemblages (Excavation Area A and Column Sample) using the Shannon-Wiener index of heterogeneity [$H=-\sum Pi(lnPi)$] and the Shannon index of evenness ($e = H/lnS$) (see earlier section for a methods description). The Column Sample was recovered from an from an area adjacent to the Excavation Area A assemblage, and therefore, should possess a taxonomic composition. The Excavation Area A assemblage was passed through 0.64 cm (1/4 in) mesh, whereas the Column Sample was passed through 0.32 cm (1/8 in) mesh. The use of differing sieve sizes resulted in lower heterogeneity (diversity) and evenness (richness) values among the Excavation Area A (0.64 cm, 1/4 in mesh) assemblages compared to the Column Sample (0.32 cm, 1/8 in mesh) assemblages (Tables 8.18, 8.19; Figure 8.13). Smaller taxa (e.g. Pacific herring, saffron cod, eulachon, and small sculpins) are underrepresented in the Excavation Area A assemblage. Therefore, because the Rice Ridge fish bones were passed through 0.64 cm (1/4 in) mesh, the assemblage may also be under represented by the same smaller fish taxa. However, the larger taxa that typically comprise most of the assemblage (e.g. salmon, Pacific cod, flat fishes, and large sculpins) are not affected by sieve size differences. Therefore, comparisons of the Rice Ridge and Mink Island fish bone assemblages are limited to larger fish taxa. Because the Settlement Point assemblage was passed through the same mesh sieve size as the Mink Island assemblage (0.32 cm, 1/8 in), the two assemblages are directly comparable, and the discussion includes all fish taxa.

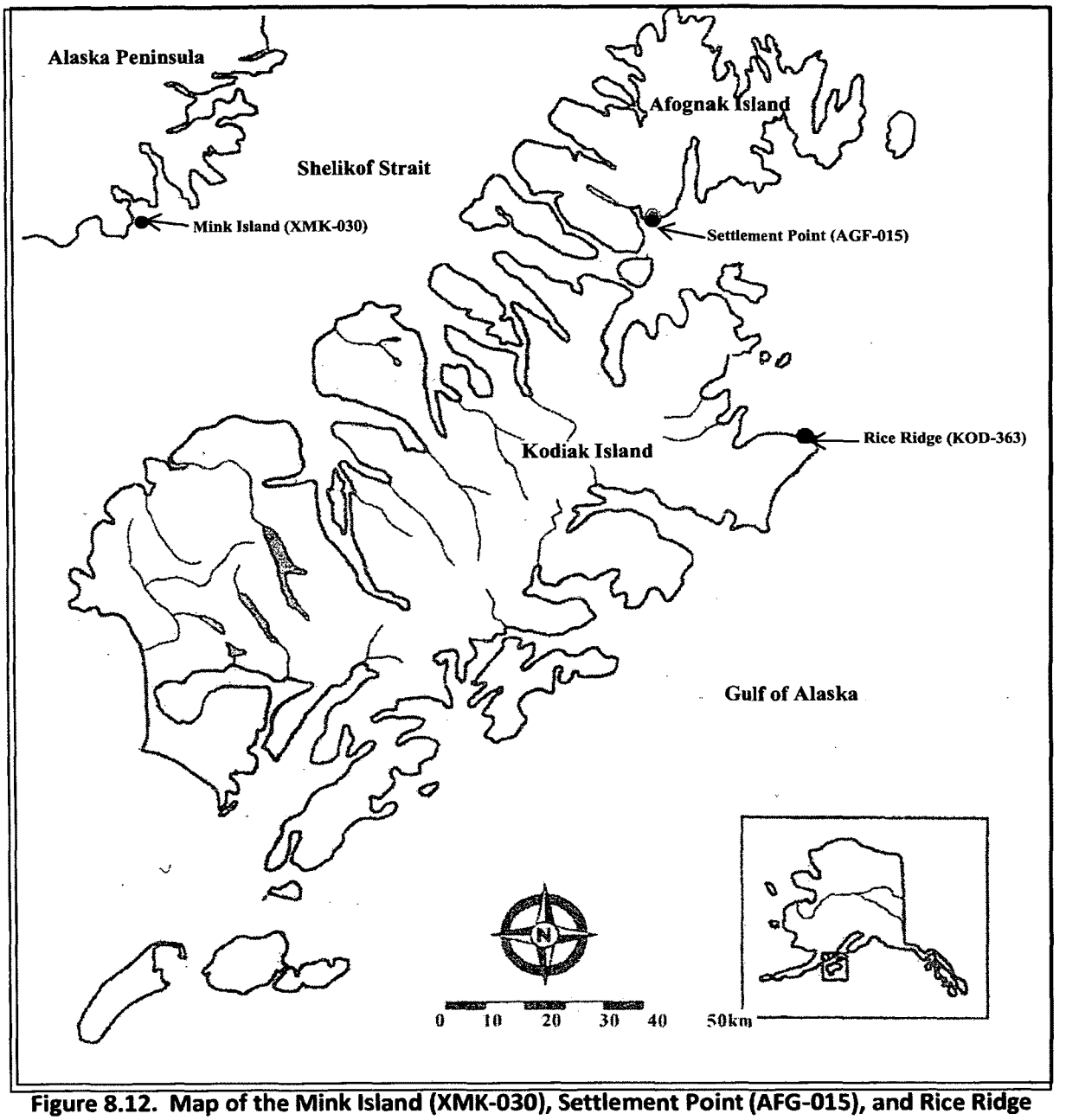


Figure 8.12. Map of the Mink Island (XMK-030), Settlement Point (AFG-015), and Rice Ridge (KOD-363) sites.

Table 8.18. Shannon-Wiener Index of Heterogeneity values of Mink Island fish bones excavated from Excavation Area A (0.64 cm, 1/4 in mesh) versus the Column Sample (0.32 cm, 1/8 in mesh).

Shannon-Wiener Index of Heterogeneity H=-∑Pi(lnPi)		
Temporal/Cultural Zone	Excavation Area A (1/4 in mesh)	Column Sample (1/8 in mesh)
UM I (750-455cal. BP)	1.2	1.6
UM II (1000-750 cal. BP)	1.05	1.09
UM III (1600-1000 cal. BP)	1.05	1.47

Table 8.19. Shannon Index of Evenness values of Mink Island fish bones excavated from Excavation Area A (0.64 cm , 1/4 in mesh) versus the Column Sample (0.32 cm, 1/8 in mesh).

Shannon Index of Evenness e = H/lnS		
Temporal/Cultural Zone	Excavation Area A (1/4 in mesh)	Column Sample (1/8 in mesh)
UM I (750-455 cal. BP)	0.41	0.68
UM II (1000-750 cal. BP)	0.40	0.44
UM III (1600-1000 cal. BP)	0.41	0.51

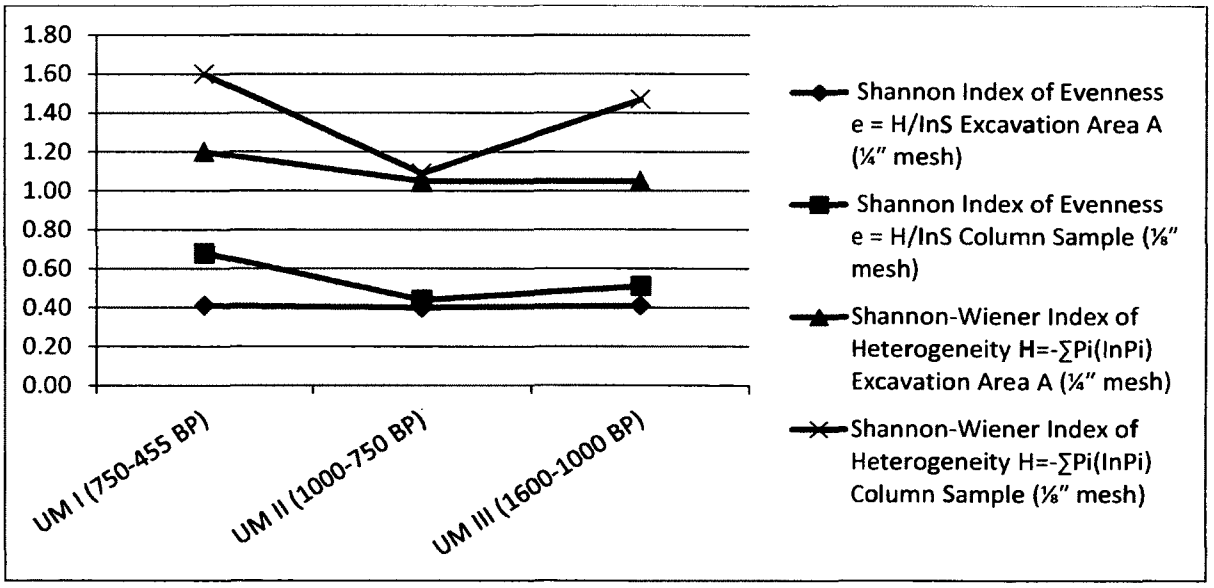


Figure 8.13. Shannon-Wiener Index of Heterogeneity and Shannon Index of Evenness values of Mink Island fish bones excavated from Excavation Area A (0.64 cm, 1/4 in mesh) versus the Column Sample (0.32 cm, 1/8 in mesh). Radiocarbon age ranges are calibrated (2-sigma).

Results: Mink Island versus Rice Ridge (Ocean Bay II and I)

NISP values of the Mink Island LM II (Ocean Bay I, 6700-5400 cal. BP) and LM I (Ocean Bay II, 5400-4100 cal. BP) assemblages are presented with the Rice Ridge LC (Ocean Bay I, 5920-5720 cal. BP) and LA (Ocean Bay II, 5050-4100 cal. BP) assemblage values in Table 8.20. As Figure 8.14 illustrates, the Mink Island (LM II) and Rice Ridge (LC) Ocean Bay I (6700-5400 cal. BP) assemblage %NISP values are different. The Mink Island assemblage is comprised primarily of Pleuronectidae (60%), whereas the Rice Ridge site is composed mostly of Gadidae (75%). The remaining larger fish taxa (e.g. Cottidae, Salmonidae, and Scorpaenidae) %NISP values are, however, similar among the two assemblages. The Mink Island occupants likely procured small flatfishes using hook and line from beaches or other nearshore locations, whereas the Rice Ridge occupants likely procured Gadidae (mostly Pacific cod) using hook and line from nearshore marine patches. Therefore, the NISP values indicate that the Mink Island occupants employed different fishing strategies than the Rice Ridge occupants during the Ocean Bay I period.

During Ocean Bay II (5400-4100 cal. BP), the NISP values among the Mink Island (LM I) and Rice Ridge (LA) assemblages are also different (Table 8.20). As Figure 8.15 illustrates, the Mink Island assemblage is comprised of a mixture of Gadidae (46%), Cottidae (30%), Salmonidae (15%), and Pleuronectidae (7%), whereas the Rice Ridge assemblage is composed primarily of Salmonidae (57%) and Gadidae (40%). The Mink Island occupants likely captured fishes using hook and line from nearshore marine patches on a year-round basis. The relatively small percentage of Salmonidae (15%) suggests that Mink Island occupants briefly used riverine patches during the spring and summer. The Rice Ridge occupants, however, likely spent more time and effort in riverine patches during the spring and summer to procure Salmonidae (57%). However, the relatively large percentage of Gadidae (40%) within the Rice Ridge assemblage suggests that the occupants also utilized nearshore marine patches throughout the year during the Ocean Bay II period.

Because the discussion among the Rice Ridge and Mink Island assemblages is limited to the larger fish taxa (e.g. Gadidae, Salmonidae, Cottidae, and Pleuronectidae), the results are not biased by mesh sieve size differences. The Mink Island occupants focused on different resource

patches than the Rice Ridge occupants throughout the Ocean Bay I and Ocean Bay II periods. The Mink Island occupants shifted their focus from shore-fishing during Ocean Bay I to boat-fishing in nearshore marine patches during Ocean Bay II. Riverine patches were used sparingly by Mink Island occupants during both Ocean Bay periods. The Rice Ridge occupants, however, focused on nearshore marine patches during Ocean Bay I, and split their focus between nearshore marine and riverine patches during Ocean Bay II.

Table 8.20. NISP and %NISP values of family-level fish bones from the Mink Island (XMK-030) and Rice Ridge (KOD-363) sites. Fish faunal assemblages date to Ocean Bay (I and II) tradition. Rice Ridge data was obtained from Kopperl (2003; pp. 117, Table 4.1; pp. 167, Table 5.1).

Ocean Bay I & II Assemblages	Mink Island (LM I) (OB II) (5400-4100 cal. BP)	Rice Ridge (LA) (OB II) (5050-4100 cal. BP)	Mink Island (LM II) (OB I) (6700-5400 cal. BP)	Rice Ridge (LC) (OB I) (5920-5720 cal. BP)
Taxon	**NISP**	**NISP**	**NISP**	**NISP**
Clupeidae	8	2	4	9
Cottidae	1667	19	204	56
Gadidae	2526	391	265	575
Hexagrammidae	66	5	26	0
Osmeridae	0	0	0	0
Pleuronectidae	408	7	1163	18
Salmonidae	832	551	259	110
Scorpaenidae	26	0	9	0
Total	**5533**	**975**	**1930**	**768**

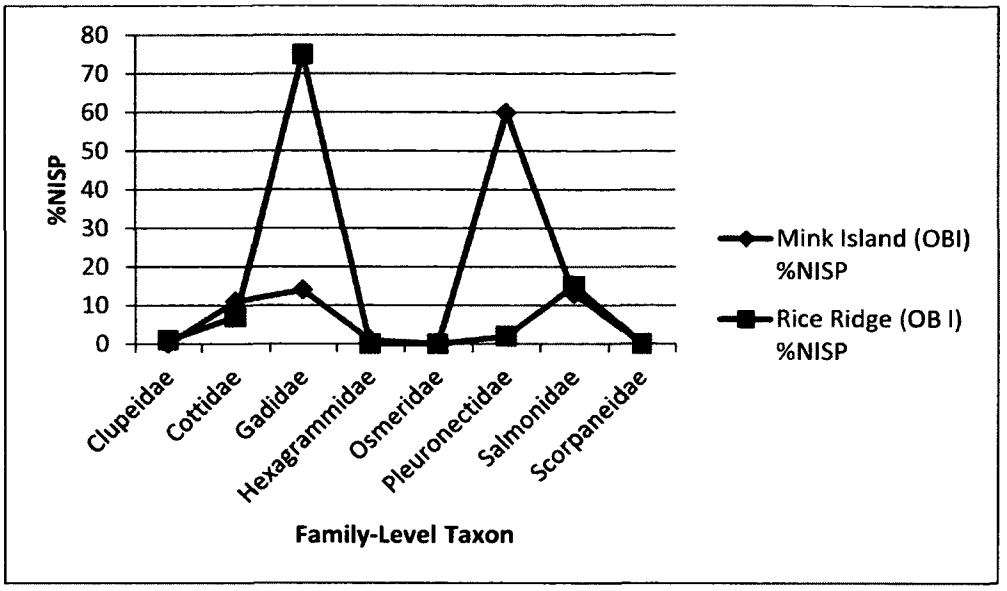


Figure 8.14. %NISP values of family-level fish bones from the Mink Island (LM II) and Rice Ridge (LC) sites. Fish Bones belong to the Ocean Bay I tradition. The Rice Ridge data was obtained from Kopperl (2003; pp. 117, Table 4.1 and pp. 167, Table 5.1).

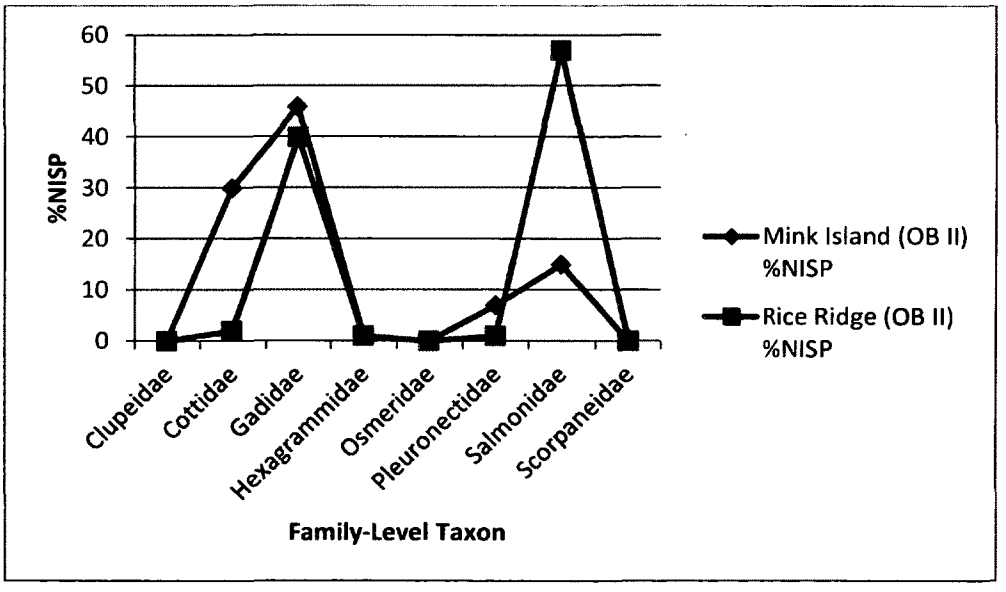


Figure 8.15. %NISP values of family-level fish bones from the Mink Island (LM I) and Rice Ridge (LA) sites. Fish Bones belong to the Ocean Bay II tradition. The Rice Ridge data was obtained from Kopperl (2003; pp. 117, Table 4.1 and pp. 167, Table 5.1).

Results: Mink Island versus Settlement Point (Thule/Koniag)

Mink Island UM I (Thule/Koniag 750-455 cal. BP) and HF.5 (Thule/Koniag, 640-510 cal. BP) assemblage NISP values are presented with the Settlement Point (Thule/Koniag, 590-330 cal. BP) assemblage NISP values in Table 8.21. Because each of the fish bone assemblages were passed through 0.32 cm (1/8 in) mesh, they are directly comparable. As Figure 8.16 illustrates, %NISP values among the Mink Island HF.5 and the Settlement Point (Midden) assemblages are similar; however the Mink Island UM I assemblage is different.

The Settlement Point (midden) assemblage is composed of Gadidae (57%), Salmonidae (36%), Cottidae (6%), and Pleuronectidae (1%) (Figure 8.16). The dominance of Gadidae and Salmonidae within the assemblage indicates that Settlement Point occupants likely used the riverine environment to procure salmon (using net and weir technologies) during the spring and summer months. They also likely used nearshore marine environment to obtain Pacific cod via hook and line technology during the remaining months. The relatively small percentage of Cottidae (6%) and Pleuronectidae (1%) within the assemblages suggests that these taxa were likely caught as by-catch while fishing for Pacific cod. The absence of other small fish taxa (e.g. Clupeidae, Hexigrammidae, and Osmeridae) suggests that the Settlement Point occupants most likely did not fish from shore near the mouth of salmon streams. The nearshore marine taxa were likely captured from watercraft.

The Mink Island HF.5 assemblage is comprised of a mixture of Salmonidae (42%), Gadidae (34%), Cottidae (15%), Clupeidae (7%), and Pleuronectidae (2%) (Figure 8.16). The dominance of Salmonidae and Gadidae among the Mink Island HF.5 assemblage also demonstrates that the occupants used a mixture of riverine and nearshore marine resource patches. They used the riverine patch to procure salmon during the spring and summer (using net and weir technologies), whereas they used nearshore marine patches to obtain Pacific cod using hook and line throughout the rest of the year. The large percentages of Salmonidae (42%)and Clupeidae (7%) suggest that the HF.5 occupants focused their procurement efforts during the spring and fall.

The Mink Island UM I assemblage is different from the Settlement Point (midden) assemblage. The UM I assemblage contains a mixture of Cottidae (48%), Gadidae (18%),

Salmonidae (17%), Clupeidae (13%), and Pleuronectidae (4%) (Figure 8.16). The Settlement Point assemblage is dominated by Gadidae and Salmonidae (see previous paragraph) (Figure 8.16). The large number of Pacific herring (Clupeidae), saffron cod (Gadidae), Pacific cod (Gadidae), and sculpins (Cottidae) associated with the UM I assemblage, suggests that the Mink Island occupants exploited nearshore marine patches (likely captured near the mouth of salmon streams during the spring and summer).

Table 8.21. NISP values of family-level fish bones from the Mink Island (XMK-030) and Settlement Point (AFG-015) sites. Fish faunal assemblages date to Thule/Koniag tradition. Settlement Point data was obtained from Partlow (2000; pp. 74, Table 4.01; pp. 145, Table 7.01).

Thule/Koniag Assemblages	Mink Island (XMK-030) HF.5 (640-510 cal. B.P.)	Mink Island (XMK-030) UM I (750-455 cal. BP)	Settlement Point (AFG-015) (Midden) (590-330 cal. BP)
Taxon	**NISP**	**NISP**	**NISP**
Clupeidae	334	28	0
Cottidae	741	104	274
Gadidae	1690	38	2840
Hexagrammidae	9	1	3
Osmeridae	3	0	0
Pleuronectidae	101	8	48
Salmonidae	2129	37	1783
Scorpaenidae	12	0	0
Total	**5019**	**216**	**4948**

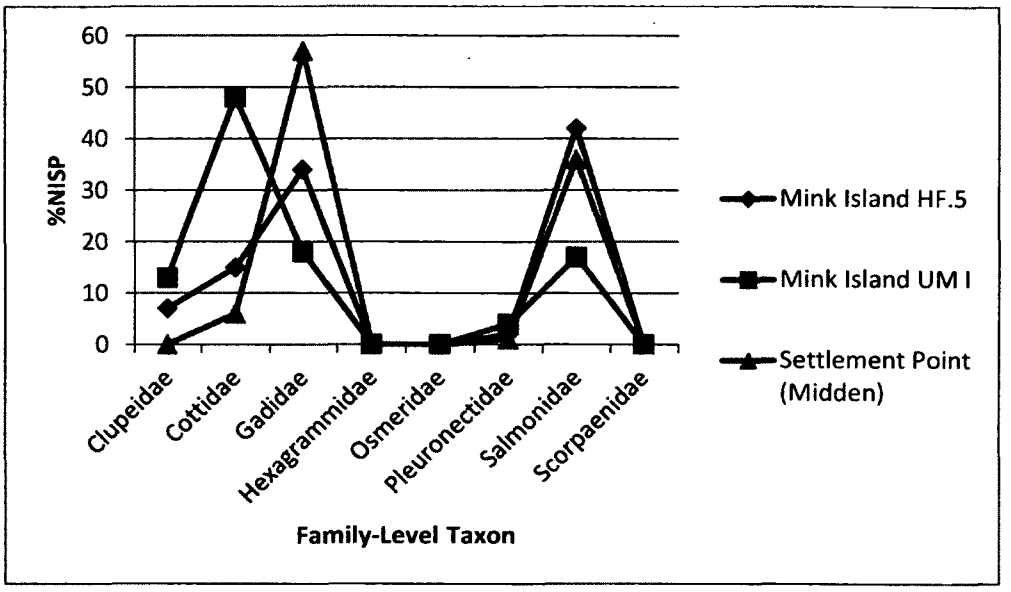


Figure 8.16. %NISP values of family-level fish bones from the Mink Island (UM I and HF.5) and Settlement Point (midden) sites. Fish Bones belong to the Thule/Koniag tradition. The Settlement Point data was obtained from Partlow (2000; pp. 74, Table 4.01; pp. 145, Table 7.01).

Discussion

The differences among Ocean Bay fish bone assemblages at Mink Island and Rice Ridge appear largely structured by different resource patch configurations and patch use. The transition from Ocean Bay I to Ocean Bay II at Mink Island appears different from the transition at Rice Ridge. Both Rice Ridge assemblages appear dominated by salmon and cod, the former becoming more important (increasing from 15% to 57% of total NISP). Where the Mink Island assemblage was more varied throughout both periods; however, a change from small flatfishes to Pacific cod and sculpins, suggests an increase in fishing nearshore marine resource patches using boats during the latter Ocean Bay II. These patterns suggest considerable variability in Ocean Bay I and II fish strategies that are likely conditioned by seasonal resource use patterns as well as local resource patch size and location.

For the later Thule/Koniag tradition, the fish bone assemblages appear more similar, but exhibit some variability. This variability appears tied to distinct fishing technologies, seasonality,

and resource patch use. The Settlement Point and Mink Island HF. 5 occupants had two main fishing strategies; 1) Net and weir fishing in spring and summer on salmon streams, and 2) Year-round hook and line fishing in nearshore marine patches. The Mink Island UM I occupants had three main fishing strategies; the two mentioned above and 3) hook and line fishing at the mouth of salmon streams during the spring and summer.

Chapter 9. Conclusions

In this final chapter, I review and discuss the results of my dissertation research. Chapters 6 and 7 represent the first attempt to combine zooarchaeological and stable isotopic methods to evaluate the effects of taphonomic agents on archaeological fish bones. This novel approach provides more detailed preservation data than is typically available using traditional zooarchaeological methods. Moreover, the fish-specific stable isotopic pretreatment, sample selection, and quality control assessments methods introduced in this dissertation provide a means to obtain stable isotope values that are free of contamination and preservation biases.

Zooarchaeological methods were used in Chapter 6 to evaluate the effects of biostratinomic and diagenic agents on fish bones. BVD measurements and abundance measures were compared to identify the agents primarily responsible for structuring the Pacific cod and Pacific salmon assemblages. The factors that affect preservation potential (assessed through completeness %) were also identified. The results from these analyses were used to refine fish bone abundance values at Mink Island.

Stable isotopic methods were used in Chapter 7 to assess the effects of biostratinomic and diagenic agents on fish bones. Stable isotopic pretreatment methods were used to determine if color-affecting contaminants could be removed from archaeological bones so the cooking/burning stages could be assessed using Petchy and Higham's (2000) method. Stable isotopic methods were also used to identify which Pacific cod skeletal element possess the lowest average preservation/contamination ranking, and is therefore, best suited for stable isotope analysis. The results were used to guide stable isotope sample selection criteria. Finally, stable isotopic methods were used to validate the modified Bell *et al.* (2001) stable isotope pretreatment method for archaeological fish bones. Quality control indicator values that were adjusted to account for the distinct structural and chemical composition of cold-water-adapted fish bones were used to assess sample quality.

The results of the taphonomic analysis in Chapters 6 and 7, which identified the skeletal element- and taxa-specific preservation biases, were used to refine abundance estimates of Mink Island fish bones in Chapter 8. The fish bone abundance estimates were then used to assess Mink Islands' fit within the region four-stage resource depression and intensification

model (e.g. Fitzhugh, 1996; Kopperl, 2003; Partlow, 2000). Taxonomic diversity and abundance estimates were calculated to determine if interactions between humans and fishes changed over time. Linear regression analysis on Pacific cod quadrates was used to identify whether resource depression/s occurred at Mink Island. Finally, Salmon Index, Evenness Index, and skeletal element representation data were used to determine if resource intensification (on salmon) occurred at Mink Island. The Mink Island fish bone abundance data was then compared to the fish bone abundance data from Rice Ridge and Settlement Point to evaluate Mink Islands' fit within the regional pattern.

Concluding remarks in this chapter identify the areas in need of additional laboratory and field-based research. A discussion that focuses on the role that resource depression and intensification played in changing social organization at Mink Island is also included. General observations concerning the use of archaeological fish bone data for zooarchaeological and stable isotope analyses concludes this dissertation.

Taphonomic Analysis Using Zooarchaeological Methods

The taphonomic analysis of Pacific cod and salmon remains recovered from Mink Island revealed that the two species were differently affected by biostratinomic agents. The densest Pacific cod skeletal elements are most numerous, and, therefore, diagenic agents (BVD-mediated attrition) played the largest role in structuring the assemblage. The densest salmon skeletal elements are not the most numerous, and, therefore, biostratinomic agents (e.g. processing salmon for storage) played the largest role in structuring the assemblage.

Taphonomic analysis also revealed that %NISP values of non-vertebrae and fish skeletal elements that are too fragmentary to identify beyond class changed significantly ($p<.05$) over time. Therefore, diagenic agents played the largest role in structuring the Mink Island fish bone assemblage. Taphonomic analysis also revealed that changes in the %NISP values of fish vertebrae are not significant ($p\geq.05$), which demonstrates that fish vertebrae are more resistant to diagenic destruction than other non-vertebrae skeletal elements.

Mean completeness % values are significantly correlated ($p<.05$) with skeletal element burial duration. Although there is a general trend towards lower mean completeness % over

time, there is a reversal within the Lower Midden assemblage. Skeletal elements from LMI (5400-4100 cal. BP) are more fragmented than skeletal elements from LM II (6700-5400 cal. BP). This pattern is opposite of expected If diagenic agents were the primary destructive force. Therefore, the LM II assemblage was either more intensely affected by diagenic agents (i.e. wave action attrition, lower pH values, etc.) or the assemblage was more intensely affected by biostratinomic agents (i.e. differential processing).

Mean completeness % values differed significantly ($p<.05$) among the Mink Island fish taxa. Pacific cod, which have the highest BVD values (of those that are known), possess the lowest mean completeness % values. Whereas salmon, which have the lowest BVD values (of those that are known), possess the highest mean completeness % values. The results are opposite of expected if diagenic agents were primarily responsible for structuring the assemblage. Therefore, Pacific cod skeletal elements were more highly processed (i.e. cooked, butchered, etc.) than the other taxa, which left them more vulnerable to the effects of diagenic agents. Moreover, the salmon skeletal elements that were deposited within the midden were less processed (i.e. dried) than other taxa.

Mean completeness % values also differed significantly ($p<.05$) among anatomical regions. However, because mean completeness % and NISP values are unevenly distributed within and across anatomical regions, the data are skewed. When combined, uneven distribution of mean completeness % and NISP values demonstrates that anatomical regions are inappropriate aggregation units for assessing fish bone preservation potential. Preservation potential is linked to something other than anatomical region variability.

The mean completeness % value of robust skeletal elements is significantly ($p<.05$) lower than the mean completeness % value of non-robust skeletal elements. This pattern is opposite of expected if the presence of skeletal element robusticity augmented preservation potential. Skeletal element robusticity is, however, significantly correlated ($p<.05$) with higher identifiability potential, as indicated by higher NISP values. Robust skeletal elements contain structural features (i.e. tooth structures, vertical struts, jaw articular structures, and preopercular posterior wing spines) that allow the skeletal element to retain its identifiability despite being highly fragmented. Therefore, even highly fragmented pieces of robust skeletal

elements are identifiable to the family level. Non-robust skeletal elements lack these highly diagnostic features and become too fragmentary to identify beyond class faster.

Finally, Mean completeness % values differ significantly ($p<.05$) across the three 2-D shape-based categories (e.g. compact, intermediate, and elongated). Compact skeletal elements possessed significantly ($p<.05$) higher mean completeness % values than intermediate and elongated skeletal elements. However, the large overlap in SD values and high CV values associated with the shape categories demonstrate that the 2-D shape-based categories are not the best method for assessing preservation potential. Skeletal element thickness plays an essential role and must be factored into shape-based calculations.

This taphonomic analysis revealed that a combination of biostratinomic and diagenic agents structured the Mink Island fish bone assemblage. Differential processing (i.e. cooking and butchering) and differential disposal (i.e. processing for storage) of the fish taxa and skeletal elements resulted in differential preservation and recovery potential. Those taxa and skeletal elements that were more highly processed were less able to withstand the effects of diagenic agents after they were buried. Once the taxa and skeletal elements were buried, they were affected by the same diagenic agent action that increased over time.

Taphonomic Analysis Using Stable Isotopic Methods

Taphonomic analysis using stable isotopic methods also revealed several interesting and surprising results. The cooking/burning stage assessment revealed that Petchey and Higham's' (2000) color-based method is not suitable for identifying the temperature to which archaeological fish bones were heated. Absorption of diagenic contaminants from the burial environment (e.g. humic acid, fulvic acid, and humins) affect color, and therefore, must be removed before the cooking/burning stage may be assessed. However, because stable isotope pretreatment methods cannot remove all contaminants (e.g. humins) without applying heat, this method is not suitable. Therefore, other methods (e.g. SEM and X-Ray diffraction) are better suited to assess cooking/burning stages.

The preservation assessment (e.g. physical appearance, BB%N, BB%C, and % collagen yield) revealed that preservation potential is not augmented by increased BVD. The densest

bones were not the best-preserved bones. With the exception of the physical appearance class, preservation potential differed significantly ($P<.05$) among completeness % categories. As fragmentation increases, preservation decreases. As long as the outer cortical bone retains its integrity, preservation is good. If the cortical bone is breached, preservation decreases as ions are leached from the bone. With the exception of physical appearance class, preservation potential also differed significantly ($p<.05$) among radiocarbon year BP categories. Modern skeletal elements are significantly ($P<.05$) better preserved than the Mink Island skeletal elements. Skeletal elements were leached quickly after being buried. The rate of leaching decreased as the skeletal elements achieved chemical equilibrium with the burial environment. As the combined effects of compaction and leaching affected fish bones associated with the Ocean Bay I assemblage (5340 cal. BP) more than other assemblages, they possess decreased preservation potential.

Preservation is best assessed using BB%N, BB%C, and % collagen yield. Physical appearance class assessments did not accurately predict overall preservation, and therefore should not be used. Because % collagen yield may be determined during the stable isotope pretreatment process, is easy to calculate, and does not require additional analysis, it is the preferred method and should be calculated before sending samples off for $\delta^{13}C$ and $\delta^{15}N$ analysis

The carbon contamination assessment (e.g. actual versus expected BB%C values) revealed that carbon contamination differs significantly (negatively, $p<.05$) among BVD categories. The most dense bones tend to be the most contaminated bones and the least dense bones tend to be the least contaminated. Therefore, increased BVD values are not associated with decreased contamination values. There are, however, significant ($p<.05$) differences in carbon contamination among completeness % categories. As skeletal elements become more fragmentary, contamination increases. As long as the outer cortical bone retains its integrity, contamination remains low, however if the cortical bone is breached, contaminates gain access to the interior portion of the bone. There are also significant differences ($p<.05$) in carbon contamination among radiocarbon years BP categories. Skeletal elements at the bottom and the top of the shell midden tend to be more contaminated than those within the middle of the midden. Skeletal elements at the bottom tend to be more affected by compaction and leaching.

As rainwater percolates through the shell midden, water-soluble carbon contaminants travel through the matrix until they settle at the base of the midden. As the shell midden matrix dries, the contaminants are absorbed into the open pore spaces. Skeletal elements near the surface also tend to be more affected by trampling and contamination. These skeletal elements are adjacent to the soil humus layer, which causes them to degrade and become contaminated faster.

The analyses revealed that preservation and contamination potential is connected with completeness % values and burial duration. Because the reconstruction of ecosystem structure and function typically requires testing of fish bones from multiple radiocarbon-dated levels that span the length of occupation at an archaeological site, it is imperative that only the most complete skeletal elements be chosen for stable isotope analysis. These skeletal elements should be free of visible contaminants, be un-burned, have a smooth outer cortical bone layer, and have a known relationship between individual skeletal element measurements and fork length. Dentaries have the highest potential to meet these qualifications. As long as these qualifications are met, stable isotope values should reflect changes in ecosystem structure and function rather than differences in contamination and preservation.

The assessment of the Bell *et al.* (2001) stable isotope pretreatment method, as modified, revealed that it is suitable for use with archaeological Pacific cod bones. However, among modern samples and complete archaeological skeletal elements, the modified Bell *et al.* (2001) method must be adjusted. The samples should be retained in the 0.5M HCl wash for an additional 10 minutes to insure complete demineralization. These samples possess an intact outer cortical bone layer that requires additional time for the HCl to breach. Skeletal elements that are fragmentary (e.g. 90-10% complete) have compromised cortical bone layers, and therefore the acid is able to enter the interior portion of the bone and demineralization begins on inside surfaces. Therefore, for these samples, the modified Bell *et al.* (2001) pretreatment method does not need adjustment.

Regardless of the specific pretreatment methods used to prepare fish bones for stable isotope analysis, it is essential to assess the quality (e.g. %C by weight, %N by weight, atomic C: N) of the stable isotope ($\delta^{13}C$ and $\delta^{15}N$) values. The raw data that accompanies the stable isotope values (e.g. %C by weight and %N by weight) is used to determine atomic C: N [(%C/%N)

x 1.167], which is the best indicator of preservation and contamination. Because fish bones have a different structural and chemical composition compared to mammal bones, the quality control indicators must be adjusted accordingly. Fish bones possess lower %C by weight and higher %N by weight values than mammal bones. Therefore, atomic C: N values are also lower among fish bones.

Interactions among Humans and Fishes at Mink Island

Because the ways that biostratinomic and diagenic agents affected fish bone preservation were addressed in Chapters 6 and 7, it is possible to explore human/fish interactions at Mink Island in a less biased manner. Interactions were uncovered using a four-stage resource depression and intensification model that was derived from optimal foraging theory. The model tested three hypotheses aimed at identifying the ways that social organization changed over time at Mink Island. The first Hypothesis explored how taxonomic diversity and abundance changed over time in relation to the four stages of the resource model. The second hypothesis used changing fork length data to determine if evidence for resource depression(s) is/are present at Mink Island. The final hypothesis used taxonomic proportion, evenness, and storage data to explore evidence of resource intensification of salmon and other marine taxa.

The abundance values (NISP, MNE, and MNI) demonstrate a change over time in taxonomic diversity at Mink Island. As different recovery and sampling strategies resulted in different abundance values, it is not presently possible to track temporal changes in abundance. The LM II (Ocean Bay I) assemblage fits the resource depression and intensification model. Mink Island occupants focused on procuring large-bodied, high-ranked prey (e.g. sea mammals) and small flatfishes (Pleuronectidae) were likely captured (using individual composite hooks) from beaches or other nearshore locations. However, fishes were not the focus of procurement efforts during this stage. A shift in subsistence strategies is seen in the LM I (Ocean Bay II) fish bone assemblage with the marked increase in Pacific cod (Gadidae) and Sculpins (Cottidae). Pacific cod and sculpins were likely captured (using individual composite hooks) in nearshore marine resource patches while waiting for opportunities to procure high-ranking sea mammals.

The same general pattern, where nearshore marine patches were the focus of foraging efforts, continues through UM III (Stage III, Norton/Kachemak) and UM II (Stage IV, Thule/Koniag). This is the point where the Mink Island assemblage differs from model predictions. The relatively low salmon abundance reveals that they were not the procurement focus of Mink Island occupants during this stage. Although riverine resource patches were exploited, they were not the focus during this period (UM II). The shift during UM I (Stage IV, Thule/Koniag), represents the use of more varied resource patches, especially those closer to shore. Finally, the large percentage of salmon within the HF.5 assemblage (Stage IV, Thule/Koniag) demonstrates that the occupants utilized (using net and weir technologies) riverine resource patches along the Shelikof Strait coast more during this period. However, the large number of Pacific herring, saffron cod, Pacific cod, and sculpins within the assemblage reveals that the occupants exploited a mixture of resource patches during the spring and summer.

The second hypothesis tested in Chapter 8 used changes in fork lengths (e.g. Orchard, 2003) to determine if Pacific cod showed signs of over-exploitation (e.g. resource depression). Increased harvest pressure by foragers is visible in the archaeological record as a decrease in the mean fork length derived from maximum dimensions of certain skeletal elements (e.g. quadrate) (Klein and Cruz-Uribe, 1984). A decrease in fork length over time may be the result of increased human harvesting pressure or climatic fluctuations (Kopperl, 2003). Therefore, it is essential to link changes in environmental conditions with changes in fish bone sizes to determine if fluctuations in body sizes are the result of human exploitation pressure or other environmental factors (Reitz and Wing, 1999; Grayson *et al.*, 2001).

As the four-stage model predicts, Pacific cod fork lengths are smaller during Stage II (LM I, Ocean Bay II). The mean fork length values, associated with Stage II are significantly ($p<.05$) smaller than are their Stage IV (Thule/Koniag, UM I) counterparts. A combination of human harvesting pressure and climate change was responsible for patterning the fork length data. Resource depression during Stage II likely occurred when occupants exploited near-shore patches (located near sea mammal rookeries) that were also affected by cooler sea surface temperatures.

Except for the HF.5 assemblage, the mean fork length increased over time, which is as expected if Mink Island occupants used a combination of high-ranking nearshore marine patches

and low-ranking riverine resource patches. The decrease in mean fork length associated with the HF.5 assemblage may be explained by use of differential capture locations. If Mink Island occupants captured a larger portion of Pacific cod specimens from beaches near salmon procurement locations, they may have captured individuals that were smaller than those that were available by watercraft. The decrease in mean fork length may also have been caused by climate change associated with the Little Ice Age. However, because Pacific cod are abundant within the HF.5 assemblage, the decrease in mean fork length is more likely associated with resource patch choices.

The resource intensification hypothesis was also tested in Chapter 8 by measuring change over time of taxonomic proportions, heterogeneity, and evenness. An increase in the percentage of salmon coupled with a decrease in evenness and heterogeneity is indicative of resource intensification on salmon (Partlow, 2000). Additionally, skeletal element representation (e.g. the ratio of cranial to post-cranial skeletal elements), may be used to identify resource intensification (Butler and Chatters, 1994). The combined data used here revealed that salmon intensification did not occur at Mink Island during any period. There is an increase in salmon abundance and an associated decrease in heterogeneity and evenness associated with the HF.5 assemblage (640-510 cal. BP). However, this increase is not large enough to suggest resource intensification focused on salmon. Marine fish taxa continued to be abundant during this period.

The salmon index data suggests that riverine patches along the Shelikof Strait coast were not extensively exploited until Stage IV (Thule/Koniag). However, the Mink Island occupants were still exploiting marine patches during this period. Therefore, the riverine patches were used on a seasonal basis (late spring and summer). Marine patches were exploited during the remaining months. As small flatfishes, sculpins, and cods were available from nearshore locations by hook and line on Mink Island year-round, they provided fresh protein during the lean months (Crowell *et al.*, 2003). When the salmon index, heterogeneity, and evenness data are combined with the taphonomic evidence of salmon processing (see Chapter 6), it is clear that humans were primarily responsible for structuring the salmon assemblage during all periods.

Suggestions for Future Research

Discussion of the results presented above would benefit from several lines of additional research. Regional culture change comparisons based on fish bone assemblages would benefit from additional research that employs fish-specific recovery, sieving, and analytical methods. Future fish-specific research should focus on excavating coastal sites (especially on the Shelikof Strait coast), which employ a 0.32 cm (1/8 in) mesh sieving strategy. Analysis of recovered fish bones should include a taphonomic component.

Additional archaeological investigation focusing on identifying spatial distributions of fish bones at Mink Island over the past 1500 years would also be a benefit. These excavations could be used to determine if the lack of evidence for resource intensification on salmon at Mink Island is a function of the sampling strategy previously employed. Additional radiocarbon dates from these excavations would also be valuable, as it would refine the timing of site abandonment.

Taphonomic analyses would be augmented by establishing the BVD values of additional Pacific cod and Pacific halibut skeletal elements; especially those that are abundant within archaeological assemblages and from which fork length could be reconstructed (e.g. premaxilla, pharyngeal plate, and epihyal). Furthermore, as BVD is not uniform across the surface of a skeletal element, it would be good to have multiple measurements from each skeletal element. BVD values from additional species (e.g. yellow Irish lords, northern rock soles, greenlings, rockfish, and Pacific herring) that are regularly recovered from archaeological sites are also warranted.

The development of a method for removing color-affecting contaminants from bone collagen that does not use heat to break bonds would be useful. This method would allow the color-based method (e.g. Petchey and Higham, 2000) to be used to assess the temperature to which a fish bone was heated. In the meantime, the X-ray diffraction and the SEM methods are better suited to assess cooking/burning stage.

Stable isotopic analyses using Pacific cod bones would benefit from the establishment of the amino acid sequence so that species-specific quality control indicators could be created. Although the Atlantic cod is likely a good proxy for Pacific cod (they are the same genus and are

benthic cold-water taxon), proxy data can be problematic. The establishment of the amino acid sequence of other marine fish taxa regularly recovered from regional archaeological sites (e.g. yellow Irish lords, northern rock soles, and Pacific herring) would also be valuable. Species-specific quality control values could be derived from the amino acid sequence, and stable isotopic research could be completed on these taxa.

Additional testing of the modified Bell *et al.* (2001) pretreatment method for use with archaeological fish bones is also warranted. It would be good to establish the exact length of time needed to demineralize intact (100% complete) Pacific cod skeletal elements. Supplementary analysis that establishes the effects of gelatinization (e.g. Longin, 1971) on stable isotope values and associated quality control indicators would augment this research.

Finally, this, and all analyses that focus on identifying fish bones recovered from archaeological sites in the North Pacific Ocean would benefit from the creation of an identification manual that includes the species regularly recovered from this region. The manual should also include comparison collection preparation guidelines. The caveats associated with preparing specimens for stable isotope analysis should also be outlined.

Discussion

The taphonomic component of this dissertation research revealed that when fish bones are expected to compose a large percentage of an archaeological assemblage (e.g. midden); it is essential to adjust the recovery, sieving, and analysis strategies. Without making sieving strategy adjustments, the results will be skewed in favor of larger skeletal elements from larger individuals. Because fish have a different structural and chemical composition than mammals, they are more vulnerable to the effects of taphonomic agents. Therefore, the ratio of identified bones to bones that are too fragmentary to identify beyond class tends to be much lower among fish compared to mammals. Because of this low ratio, it is essential to complete taphonomic analysis on fish bone assemblages before interpreting zooarchaeological abundance. The abundance measures that are employed must account for fragmentation differences, and therefore, MNE values should be the basis from which abundance is estimated (e.g. MNI and %MAU).

This dissertation also revealed that taphonomic analysis must be completed before using archaeological fish bones for stable isotopic analysis. Visual inspection is not suitable for assessing preservation and contamination potential. Preservation may be accurately assessed by measuring the % collagen yield, which is simple to calculate and does not require additional expensive testing. Furthermore, it is essential to check the quality of stable isotope data using indicator values (%C by weight, %N by weight, atomic C: N) that have been adjusted to reflect the distinct structural and chemical differences of cold-water fish taxa. The %C by weight, %N by weight, and the atomic C: N values should also be presented with the data so that the reader may evaluate the quality themselves. If these procedures are followed, archaeological fish bones may provide an accurate archive of past environmental conditions.

References

Ackerman, R.E., 1984. Prehistory of the Asian Eskimo Zone. In: Damas, D. (Ed.), Handbook of American Indians, Vol. 5, Arctic, Smithsonian Institution, Washington, pp. 106-118.

Ackerman, R.E., 2004. The northern archaic tradition in southwestern Alaska. Arctic Anthropology 41, 153-162.

Ackerman, R.E., Hamilton, T.D., Stuckenrath, R., 1979. Early culture complexes on the northern northwest coast. Canadian Journal of Archaeology 3, 195-208.

Ackerman, R.E., Reid, C.K., Gallison, J.D., Roe, M.E., 1985. Archaeology of Haceta Island: A Survey of 16 Timber Harvest Units in the Tongass National Forest, Southeast Alaska. Center for Northwest Anthropology, Washington State University, Pullman.

Ager, T.A., 1982. Vegetational History of Western Alaska During the Wisconsin Glacial Interval and the Holocene. In: Hopkins, D.M., Matthews, J.V., Young, S.B. (Eds.), Paleoecology of Beringia, Academic Press, New York, pp. 128-141.

Aigner, J.S., Fullem, B., Veltre, D., Veltre, M., 1976. Preliminary reports on remains from Sandy Beach Bay, a 4300-5600 BP Aleut village. Arctic Anthropology 13, 83-90.

Alexander, M., 1965. Biodegradation: Problems of molecular recalcitrance and microbial fallibility. Advances in Applied Microbiology 7, 35-80.

Ambrose, S.H., 1990. Preparation and characterization of bone and tooth collagen for isotopic analysis. Journal of Archaeological Science 17, 431-452.

Ambrose, S.H., 1993. Isotopic Analysis of Paleodiets: Methodological and Interpretive Considerations. In: Stanford, M.K. (Ed.), Investigations of Ancient Human Tissue. Gordon and Breach, Philadelphia, pp. 59-130.

Ambrose, S.H., 2000. Controlled Diet and Climate Experiments on Nitrogen Isotope Ratios of Rats. In: Ambrose, S.H., Katzenberg M.A. (Eds.), Biogeochemical Approaches to Paleodietary Analysis. Kluwer, New York, pp. 243-259.

Ambrose, S.H., Krigbaum J. 2003. Bone chemistry and bioarchaeology. Journal of Anthropological Archaeology 22, 193-199.

Ambrose, S.H., Norr, L., 1992. On stable isotope data and prehistoric subsistence in the Soconusco Region. Current Anthropology 33, 401-404.

Ambrose, W.R., 1967. Archaeology and shell middens. Archaeology and Physical Anthropology in Oceania 2, 169-187.

Ames, K.M., 1981. The evolution of social ranking on the northwest coast of North America. American Antiquity 46,789-805.

Amorosi, T., 1987. The Karluk and Uyak Archaeofaunas: An Approach Towards the Paleoeconomy of Kodiak Island, Alaska. Paper Presented at the 52nd Annual Meeting of the Society for American Archaeology, Toronto.

Anderson, D.D., 1968. A stone-aged campsite at the gateway to America. Scientific American 218, 24-33.

Anderson, D.D., 1970. Akmak: An early archaeological assemblage from Onion Portage, northwest Alaska. Acta Arctica 16, Copenhagen.

Anderson, D.D., 1972. An archaeological survey of Noatak Drainage. Arctic Anthropology 9, 66-117.

Anderson, D.D., 1984. Prehistory of North Alaska. In: Damas, D. (Ed.), Arctic, Handbook of North American Indians, Volume 5. Smithsonian Institution, Washington, pp.80-93.

Anderson, D.D., 1988. Onion Portage: The Archaeology of a Stratified Site from the Kobuk River, Northwest Alaska. Anthropological Papers of the University of Alaska 22, University of Alaska Press, Fairbanks.

Anderson, P.J., Piatt, J.F., 1999. Community reorganization in the Gulf of Alaska following ocean climate regime shift. Marine Ecology Progress Series 189, 117-123.

Armstrong, W.D., Singer, L., 1965. The composition and constitution of the mineral phase of bone. Clinical Orthopaedics 38, 179-194.

Arnesen, J.A., Gildberg, A., 2006. Extraction of muscle proteins and gelatin from cod head. Process Biochemistry 31, 697-700.

Arnold, J.E., 1992. Complex hunter-gatherer-fishers of prehistoric California: Chiefs, specialists, and maritime adaptations of the Channel Islands. American Antiquity 57, 60-84.

Arnold, J.E., 1993. Labor and the rise of complex hunter-gatherers. Journal of Anthropological Archaeology 12, 75-119.

Arnold, J.E. (Ed.), 1996. Emergent Complexity: Evolution of Intermediated Societies. International Monographs in Prehistory, Archaeological Series 9, Ann Arbor.

Ascenzi, A., 1969. Microscopy and Prehistoric Bone. In: Brothwell, D., Higgs, E. (Eds.), Science in Archaeology. Thames and Hudson, London, pp. 526-538.

Avena-Bustillos, R.J., Olsen, C.W., Olsen, D.A., Chiou, B., Yee, E., Bechtel, P.G., McHugh, T.H., 2006. Water vapor permeability of mammalian and fish gelatin films. Journal of Food Science 71, E202-E207.

Bada, J.L., 1971. Kinetics of the nonbiological decomposition and racemization of amino acids in natural waters. Advances in Chemistry 106, 309-331.

Bada, J.L., 1991. Amino acid cosmogeochemistry. Philosophical Transactions of the. Royal Society of London Biological Sciences B 333, 349-358.

Bakkala, R., King, K., Hirschberger, W., 1981. Commercial Use and Management of Demersal Fish. In: Hood, D.W., Calder, J.A. (Eds.), The Eastern Bering Sea Shelf: Oceanography and Resources Volume 2. United States Department of Commerce, U.S. Department of the Interior, United States Government Printing Office, Washington, pp. 1015-1036.

Barker, G., 1975. To sieve or not to sieve. Antiquity 49, 61-3.

Barsch, R.L., 1985. Karluk River Study. Report Submitted to the Kodiak Area Native Association, Kodiak, Alaska.

Bartram, L.E., Jr., 1993. Perspectives on Skeletal Part Profiles and Utility Curves from Eastern Kalahari Ethnoarchaeology. In: Hudson, J. (ed.), From Bones to Behavior: Ethnoarchaeological and Experimental Contributions to the Interpretation of Faunal Remains. Southern Illinois University at Carbondale Center for Archaeological Investigations Occasional Paper 21, Carbondale, pp. 115-37

Beaton, J.M., 1991. Extensification and intensification in central California prehistory. Antiquity 65, 947-951.

Behrensmeyer, A.K., 1978. Taphonomic and ecologic information from bone weathering. Paleobiology 4, 150-162.

Behrensmeyer, A.K., 1982. Time resolution in fluvial vertebrate assemblages. Paleobiology 8, 211-228.

Behrensmeyer, A.K., Gordon, K.D., Yanagi, G.T., 1986. Trampling as a cause of bone surface damage and pseudo-cutmarks. Nature 319,768-771.

Bell, L.S., Cox, G., Sealy, J.C., 2001. Determining isotopic life history trajectories using bone density fractionation and stable isotope measurements: A new approach. American Journal of Physical Anthropology 116, 66-79.

Bell, L.S., Skinner, M.F., Jones, S.J., 1996. The speed of post mortem change to the human skeleton and its taphonomic significance. Forensic Science International 82, 129-140.

Bettinger, R.L., 1991. Hunter-Gatherers: Archaeological and Evolutionary Theory. Plenum Press, New York.

Bhatnager, G., 2006. Collagen. In Talwar, G.P., Srivastava, L.M. (Eds.), Textbook of Biochemistry and Human Biology, 3rd edition, PHI Learning Private. Ltd., Delhi, India.

Bigelow, N.H., 2000. Final Report: Little Takli Island. Manuscript on file, National Park Service, Lake Clark Katmai Studies Center, Anchorage.

Bigelow, N.H., 2004. Holocene Vegetation History on Little Takli Island, Alaska. Quaternary Center, University of Alaska, Fairbanks. Report Submitted to Jeanne Schaaf, Lake Clark Katmai Studies Center, Anchorage.

Bigp, A.M., Koch, H.J., Panzawolta, S., Roverp, N., Rubinp, K., 2000. Structural aspects of the calcification process of lower vertebrate collagen. Connective Tissue Research 41, 37-43.

Binford, L.R., 1978. Nunamiut Ethnoarchaeology. Academic Press, New York.

Binford, L.R., 1981. Bones: Ancient Men and Modern Myths. Academic Press, New York.

Binford, L.R., 1984. Butchering, sharing, and the archaeological record. Journal of AnthropologicalArchaeology 3, 235-257.

Binford, L.R., Bertram, J.B., 1977. Bone Frequencies and Attritional Processes. In: Binford, L.R. (ed.), For Theory Building in Archaeology: Essays on faunal Remains, Aquatic Resources, Spatial-Analysis, and Systematic Modeling. Academic Press, New York, pp. 77-153

Black, L.T., 1977. The Konyag (the inhabitants of the island of Kodiak) by Ioasaf [Bolotov] (1794 1799) and by Gideon (1804-1807). Arctic Anthropology 14, 79-106.

Black, L.T., 1981. Volcanism as a factor in human ecology: The Aleutian case. Ethnohistory 28, 313-340.

Black, L.T., 1992. The Russian conquest of Kodiak. Anthropological Papers of the University of Alaska 24, 156-182.

Black, L.T., 2004a. Warriors of Kodiak: Military traditions of Kodiak Islanders. Arctic Anthropology 41, 140-152.

Black, L.T., 2004b. Russians in Alaska: 1732-1867. University of Alaska Press, Fairbanks.

Bobrowsky, P.T., Ball, B.F., 1989. The Theory and Mechanics of Ecological Diversity in Archaeology. In: Leonard, R.D., Jones, G.T. (Eds.), Quantifying Diversity in Archaeology. Cambridge University Press, Cambridge, pp. 4-13.

Bocherens, H., Drucker, D., Billiou, D., Moussa, I., 2005. A new approach for assessing the preservation state of bone and collagen for isotopic analysis (radiocarbon dating, carbon and nitrogen stable isotopes). L'anthropologie 109, 557-567.

Bonucci, E., Graziani, G., 1975. Comparative thermogravimetric- x-ray diffraction and electron microscope investigations of burnt bones from recent, ancient and prehistoric age. Atti della academia Nazionale dei Lincei Tendiconti, classe de scienze fisiche, matematiche e naturali 59, 517-532.

Boone, J.L., Smith, E.A., 1997. Is it evolution yet? A critique of evolutionary archaeology. Current Anthropology 39, S141-S174.

Boserup, E., 1965. The Conditions of Agricultural Growth: The Economics of Agrarian Exchange Under Population Pressure. Aldine, Chicago.

Bradley, R.S., 1999. Paleoclimatology: Reconstructing Climates of the Quaternary, Second edition. Academic Press, New York.

Brain, C.K., 1967. Bone weathering and the problem of bone pseudo-tools. South African Journal of Science 63, 97-99.

Brain, C.K., 1981. The Hunters or the Hunted? An Introduction to African Cave Taphonomy. Chicago University Press, Chicago.

Brain, C.K., Sillen, A., 1988. Evidence from the Swartkrans Cave for the earliest use of fire. Nature 336, 464-466.

Bromage, T.G., 1984. Interpretation of scanning electron microscope images of abraded bone surfaces. American Journal of Physical Anthropology 64, 161-178.

Broughton, J.M., O'Connell, J.F., 1999. On evolutionary ecology, selectionist archaeology, and behavioral archaeology. American Antiquity 64, 153-165.

Brubaker, L.B., Anderson, P.M., Hu, F.S., 2001. Vegetation ecotone dynamics in Southwest Alaska during the Late Quaternary. Quaternary Science Reviews 20, 175-188.

Bunn, H.T., 1986. Patterns of skeletal representation and Hominid subsistence activities at Olduvai Gorge, Tanzania, and Koobi Fora, Kenya. Journal of Human Evolution 15, 670-90.

Bunn, H.T., Bartram, L.E., Kroll, E.M., 1988. Variability in bone assemblage formation from Hadza hunting, scavenging, and carcass processing. Journal of Anthropological Archaeology 7, 412-57.

Bunn, H.T., Kroll, E.M., 1986. Systematic butchery by Plio/Pleistocene Hominids at Olduvai Gorge, Tanzania. Current Anthropology 27, 431-52.

Burr, D.B., 1980. The relationships among physical, geometrical and mechanical properties of bone, with a note on the properties of nonhuman primate bone. Yearbook of Physical Anthropology 23, 109-146.

Butler, V.L., 1988. Lapita Fishing Strategies: The Faunal Evidence. In: Kirch, P.V., Hunt, T.L. (Eds.) Archaeology of the Lapita Cultural Complex: A Critical Review. Thomas Burke Memorial Washington State Museum Research Report, No. 5. Seattle, pp. 99-115.

Butler, V.L., 1990. Distinguishing Natural from Cultural Salmonid Deposits in Pacific Northwest North America, Unpublished Dissertation, University of Washington.

Butler, V.L., Chatters, J.C., 1994. The role of bone density in structuring prehistoric salmon bone assemblages. Journal of Archaeological Science 21, 413-424.

Cahalane, V.H., 1959. A Biological Survey of Katmai National Monument. Smithsonian Miscellaneous Collections, Volume 138, No. 5., Smithsonian Institution Press, Washington D.C.

Calkin, D.G., 1986. Marine Mammals. In: Hood, D.W., Zimmerman, S.T. (Eds.), The Gulf of Alaska: Physical Environment and Biological Resources. Washington, D.C.: National Oceanic and Atmospheric Administration (W.S. Department of Commerce) and Minerals Management Service (U.S. Department of Interior), pp. 527-560.

Calkin, P.E., Wiles, G.C., Barclay, D.J., 2001. Holocene coastal glaciation of Alaska. Quaternary Science Reviews 20, 449-461.

Campbell, J.M., 1961. The Tuktu Complex of Anaktuvuk Pass. Anthropological Papers of the University of Alaska 9, 61-80.

Cannon, A., 1991. The Economic Prehistory of Namu: Patterns in Vertebrate Fauna. Archaeology Press, Simon Fraser University, Burnaby.

Cannon, A., 1995. The ratfish and marine resource deficiencies on the Northwest Coast. Canadian Journal of Archaeology 19, 49-60.

Cannon, D.Y., 1987. Marine Fish Osteology: A Manual for Archaeologists. Department of Archaeology Publication no. 18. Simon Fraser University, Burnaby, B.C.

Cannon, M.D., 2001. Large Mammal Resource Depression and Agricultural Intensification: an Empirical Test of the Mimbres Valley, New Mexico. PhD. Dissertation, University of Washington, Seattle.

Cannon, M.D., 1998. Contingency and agency in the growth of Northwest Coast maritime economies. Arctic Anthropology 35, 57-67.

Carlile, M.J., Watkinson, S.C., Gooday, G.W., 2001. The Fungi. Academic Press, London.

Carlson, R.L., 1979. The early period on the central coast of British Columbia. Canadian Journal of Archaeology 3, 211-227.

Casperson, M., 2009. Lower Midden Bird Bone Analysis. Masters Thesis, University of Oregon, Eugene.

Cassedy, D.F., Dekin, A.A. Jr., 1983. Sitkinak Island Survey, Final Report. Ms. On-File, University of Alaska Rasmussen Library, Fairbanks.

Casteel, R.W., 1972. Some biases in the recovery of archaeological faunal remains. Proceedings of the Prehistoric Society 38, 382-388.

Casteel, R.W., 1974a. A method for estimation of live weight of fish from the size of skeletal elements. American Antiquity 39, 94-98.

Casteel, R.W., 1974b. Use of Pacific salmon otoliths for estimating fish size, with a note on the size of late Pleistocene and Pliocene salmonids. Northwest Science 48, 175-179.

Casteel, R.W., 1976a. Fish Remains in Archaeology and Paleo-environmental Studies. Academic Press, London.

Ceci, L., 1984. Shell midden deposits as coastal resources. World Archaeology 16, 62-74.

Charnov, E., 1976. Optimal foraging: The marginal value theorem. Theoretical Population Biology 9, 474-478.

Charnov, E., Orians, G.H., Hyatt, K., 1976. Ecological implications of resource depression. American Naturalist 110, 247-259.

Child, A.M., 1995a. Microbial taphonomy of archaeological bone. Studies in Conservation 40, 19-30.

Child, A.M., 1995b. Towards an understanding of the microbial decomposition of archaeological bone in the burial environment. Journal of Archaeological Science 22, 165-174.

Child, A.M., Gillard, R.D., Pollard, A.M., 1993a. Microbial attack on collagen II: Isolation of the microorganisms and the detection of their enzymes. Journal of Archaeological Science 20, 159-164.

Child, A.M., Gillard, R.D., Pollard, A.M., 1993b. Microbially-induced promotion of amino acid racemization in bone: isolation of the microorganisms and the detection of their enzymes. Journal of Archaeological Science 20, 158-168.

Chisholm, B., Blake, M, Love, M.W., 1993. More on prehistoric subsistence in the Soconusco Region: Response to Ambrose and Norr. Current Anthropology 34, 432-434.

Clark, D.W., 1966. Perspectives in the prehistory of Kodiak Island, Alaska. American Antiquity 31, 358-371.

Clark, D.W., 1970. The Late Kachemak Tradition at Three Saints and Crag Point, Kodiak Island, Alaska. Arctic Anthropology 6, 73-111.

Clark, D.W., 1974a. Contributions to the Later Prehistory of Kodiak Island. Mercury Series, Archaeological Survey of Canada Paper No. 20. National Museum of Man, Ottawa.

Clark, D.W., 1974b. The earliest prehistoric cultures of Kodiak Island. Arctic Anthropology 11, 41-46.

Clark, D.W., 1974c. Koniag Prehistory. Tubinger Monographien zur Urgeschicht Band 1. Verlag W. Kohlammer, Stuttgart.

Clark, D.W., 1975. Technological Continuity and Change within a Persistent Maritime Adaptation: Kodiak Island, Alaska. In: Fitzhugh, W. (Ed.), Prehistoric Maritime Adaptations of the Circumpolar Zone. Mouton, The Hague, pp. 203-227.

Clark, D.W., 1979. Ocean Bay: An Early North Pacific Maritime Culture. Mercury Series, Archaeological Survey of Canada Paper 86. National Museum of Canada, Ottawa.

Clark, D.W., 1984. Pacific Eskimo: Historical Ethnography. In: Damas, D. (Ed.) Handbook of North American Indians, Vol. 5, Arctic. Smithsonian Institute Press, Washington, D.C., pp. 136-148.

Clark, D.W., 1985. Archaeological test at the Russian Three Saints Bay colony, Alaska. Historical Archaeology 19, 39-42.

Clark, D.W., 1986. Archaeological and historical evidence for an 18th century "blip" in the distribution of the Northern Fur Seal at Kodiak Island, Alaska. Arctic Anthropology 39, 114-121.

Clark, D.W., 1987. On a misty day you can see back to 1805: Ethnohistory and historical archaeology on the southeastern side of Kodiak Island, Alaska. Anthropological Papers of the University of Alaska 21, 105-132.

Clark, D.W., 1992a. Archaeology on Kodiak: The Quest for Prehistory and Its Implications for North Pacific Prehistory. In: Jordan, R.J., de Laguna, F., Steffian, A. (Eds.), Contributions to the Anthropology of Southcentral and Southwestern Alaska. Anthropological Papers of the University of Alaska 24(1-2). pp. 109-126

Clark, D.W., 1992b. "Only a skin boat load or two": The role of migration in Kodiak prehistory. Arctic Anthropology 29, 2-17.

Clark, D.W., 1994. Still a Big Story: The Prehistory of Kodiak Island. In: Bray, T.L., Killion, T.W. (Eds.), Reckoning with the Dead: The Larsen Bay Repatriation and the Smithsonian Institution. Smithsonian Institution Press, Washington, D.C., pp. 137-149.

Clark, D.W., 1997. The Early Kachemak Phase on Kodiak Island at Old Kiavak. Canadian Museum of Civilization, Mercury Series, Archaeological Survey of Canada Paper No. 155, Hull, Quebec.

Clark, D.W., 2001a. Ocean Bay. In: Peregrine, P.N., Ember, M. (Eds.), Encyclopedia of Prehistory Volume 2: Arctic and Subarctic. Kluwer Academic/Plenum Publishers, New York, pp. 152-164.

Clark, D.W., 2001b. Kodiak: Kachemak. In: Peregrine, P.N., Ember, M. (Eds.), Encyclopedia of Prehistory Volume 2: Arctic and Subarctic. Kluwer Academic/Plenum Publishers, New York, pp. 71-86.

Clark, D.W., n.d.. Ancient Afognak Precontact History and Archaeology of Afognak Bay. http://www.afognak.org/heritage/history/history-intro.php?src=ancient-afognak accessed January 2nd, 2011.

Clark, G., 1977. Archaeology of the Alaska Peninsula: The Coast of Shelikof Strait, 1963-1965. University of Oregon Anthropological Papers. Vol. 13, Eugene.

Clason, A.T., Prummel, W., 1977. Collecting, sieving and archaeozoological research. Journal of Archaeological Science 4, 171-175.

Cleland, C.E., 1966. The Prehistoric Animal Ecology and Ethnozoology of the Upper Great Lakes Region. Anthropological Papers 29. Museum of Anthropology, University of Michigan, Ann Arbor.

Cohen, M.N., 1981. Pacific Coast foragers: Affluent or overcrowded? Senri Ethnological Studies 9, 275-295.

Colley, S.M., 1990. The Analysis and Interpretation of Archaeological Fish Remains. In: Schiffer, M.B. (Ed.), Archaeological Method and Theory 2. University of Arizona Press, Tuscon, pp. 207-254.

Collins, H.B., 1984. History of Research Before 1945. In, Damas, D. (Ed.) Arctic, Handbook of North American Indians, Volume 5. Smithsonian Institution Press, Washington, D.C., pp. 8-16.

Collins, M.J., Neielsen-Marsh, C.M., Hiller, J., Smith, C.I., Roberts, J.P., Prigodich, R.V., Wess, T.J., Csapo, J., Millard, A.R., Turner-Walker, G., 2002. Survival of organic matter in bone: A review. Archaeometry 44, 383-394.

Collins, M.J., Riley, M.S., Child, A.M., Turner-Walker, G., 1995. A basic mathematical simulation of the chemical degradation of ancient collagen. Journal of Archaeological Science 22, 175-183.

Colson, I.B., Bailey, J.F., Vercauteren, M., Sykes, B.C., Hedges, R.E.M., 1997. The preservation of ancient DNA and bone diagenesis. Ancient Biomolecules 12, 109-117.

Cook, J., 1986. The Application of Scanning Electron Microscopy to Taphonomic and Archaeological Problems. In: Roe, D.A. (Ed.), Studies in the Upper Paleolithic of Britian and Northwest Europe, vol. 296. British Archaeological Reports International Series, Oxford, pp. 143-163.

Cook, S.F.,Treganza, A.E., 1950. The quantitative investigation of Indian mounds. University of California Publications in American Archaeology and Ethnology 40, 223-262.

Coupland, G., 1988. Prehistoric Economic and Social Change in the Tsimshian Area. In: Isaac, B. (Ed.), Prehistoric Economies of the Northwest Coast, Research in Economic Anthropology, sup. 3. JAI Press, Greenwich, Connecticut, pp. 211-243.

Cressmann, L., Dumond, D.E., 1962. Research on Northwest Prehistory: Prehistory in the Naknek Drainage, Southwestern Alaska. Final Report to the National Science Foundation. University of Oregon, Eugene.

Crockford, S.J., 1997. Archaeological evidence of large northern bluefin tuna, Thunnus thynnus, in coastal waters of British Columbia and Northern Washington. Fishery Bulletin 95, 11-24.

Crockford, S.J., Frederick, S.G., 2007. Sea ice expansion in the Bering Sea during the Neoglacial: Evidence from archaeozoology. Holocene 17, 699-706.

Croes, D.R., Hackenberger, S., 1988. Hoko River Archaeological Complex: Modeling Prehistoric Northwest Coast Economic Evolution. In: Isaac, B. (Ed.), Prehistoric Economies of the Northwest Coast, Research in Economic Anthropology, sup. 3. JAI Press, Greenwich, Connecticut, pp. 19-85.

Crowell, A.C., 1986. An Archaeological Survey of Uyak Bay, Kodiak Island, Alaska, Final Report. Typescript. Department of Anthropology, National Museum of Natural History, Washington, D.C.

Crowell, A.C., 1994b. Koniag Eskimo Poison-Dart Whaling. In: Fitzhugh, W.W., Chaussonnet, V. (Eds.), Anthropology of the North Pacific Rim. Smithsonian Institution Press, Washington, D.C., pp. 217-242.

Crowell, A.C., 1997. Archaeology and the Capitalist World System: A Study from Russian America. Plenum Publishing Corporation, New York.

Crowell, A.C., Mann, D.H., 1996. Human populations, sea level change, and the archaeological record of the northern Gulf of Alaska coastline. Arctic Anthropology 33, 16-37.

Crowell, A.C., Mann, D.H., 1998. Archeology and Coastal Dynamics of Kenai Fjords National Park, Alaska. National Park Service, Alaska Region. Research/Resources Management Report ARRCR/CRR 98/34.x

Crowell, A.L., Matson, M., Mann, D.H., 2003. Implications of "punctuated productivity" for coastal settlement patterns: A GIS study of the Katmai Coast, Gulf of Alaska. Alaska Journal of Anthropology 1, 62-96.

Crozier, S.N., 1987. Preliminary Excavation Report for Site 49-KOD-324. Ms. On-File, Office of History and Archaeology, Anchorage.

Crozier, S.N., 1989. Excavation at a Late Prehistoric dwelling structure on Kodiak Island, Alaska. Arctic Anthropology 26, 78-95.

Currey, J.D., 2002. Bones. Princeton University Press, Princeton.

Davis, C.W., Link, D.C., Schoenberg, K.M., Shields, H.M., 1981. Slogging, Humping and Mucking Through the NPR-A: An Archaeological Interlude, 5 Vols. University of Alaska, Anthropology and Historic Preservation Cooperative Park Studies Unit, Occasional Paper 25, Fairbanks.

Davis, S.D., 1989. Cultural Component I: In Davis, S.D. (Ed.), The Hidden Falls Site Aurora. Alaska Anthropological Association, Monograph Series, Number 5, pp. 159-198.

Davis, W.A., 1954. Archaeological Investigations of Inland and Coastal Sites of Katmai National Monument, Alaska. Report submitted to the National Park Service. Archives of Archaeology 4.

Davydov, G.I., 1976. A selection from G.I. Davydov: An account of two voyages to America. Colin Bearne (trans.), Richard A. Pierce (ed.). Arctic Anthropology 8, 1-30.

Davydov, G.I., 1977. Two Voyages to Russian America: 1802-1807. Limestone Press, Kingston.

DeGange, A.R., Sanger, G.A., 1986. Marine Birds. In: Hood, D.W., Zimmerman, S.T. (Eds.), The Gulf of Alaska: Physical Environment and Biological Resources. United States Department of Commerce, U.S. Department of the Interior. Unites States Government Printing Office, Washington. pp. 479-524.

Dekin, A.A., Jr., Cassell, M.S., Ebert, J.I., Camilli, E., Kerley, J.M., Yarborough, M.R., Stahl, P.A., Turcy, B.L., 1993. Exxon Valdez Oil Spill Archaeological Damage Assessment: Final Report. USDA/Forest Service, Juneau.

de Laguna, F., 1934. The Archaeology of Cook Inlet, Alaska. University of Washington Press, Seattle.

de Laguna, F., 1956. Chugach Prehistory: The Archaeology of Prince William Sound, Alaska. University of Washington Publications in Anthropology, vol. 13 University of Washington Press, Seattle.

DeNiro, J.J., Epstein, S., 1978. Influence of diet on the distribution of carbon isotopes in animals. Geocheochimica et Cosmochimica, acta. 42, 495-506.

Desse, J., Desse-Berset, N., 1996a. On the boundaries of osteometry applied to fish. Archaeofauna 5, 171-179.

Desse, J., Desse-Berset, N., 1996b. Archaeozoology of groupers (Epinephelinae): Identification, osteometry and keys to interpretation. Archaeofauna 5, 121-127.

Dickson, K.L., 1986. A Comparative Study of the Pelagic Food Webs in Two Newfoundland Fjords Using Stable Carbon and Nitrogen Tracers. M.S. Thesis, Memorial University, Newfoundland.

Dikov, N.N., 1968. The discovery of the Paleolithic in Kamchatka and the problem of the initial occupation of America. Arctic Anthropology 5, 191-203.

Dincauze, D.F., 2000. Environmental Archaeology: Principles and Practice. Cambridge University Press, New York.

Drennan, R.D., 2010. Statistics for Archaeologists. Plenum Press, New York.

Dubach, P., Mehta, N.C., 1963. The chemistry of soil humic substances. Soils and Fertilizers 26, 293-300.

Dumond, D.E., 1964. Archaeological Survey in Katmai National Monument, Alaska, 1963. Final report to the National Park Service.

Dumond, D.E., 1969. Toward a prehistory of the Na-Dene'. American Anthropologist 71, 857-863.

Dumond, D.E., 1971. Summary of Archaeology in the Katmai Region, Southwestern Alaska. University of Oregon Anthropological Papers. Volume 2, Eugene.

Dumond, D.E., 1977. Concluding Note: Subsistence and Seasonality. In: Clark, G. (Ed.), Archaeology on the Alaska Peninsula: The Coast of Shelikof Strait 1963-1965. University of Oregon Anthropological Papers No. 13, Eugene, pp. 101-110.

Dumond, D.E., 1979. People and Pumice on the Alaska Peninsula. In: Sheets, P.D., Grayson, D.K. (Eds.), Volcanic Activity and Human Ecology. Academic Press, New York, pp. 373-392.

Dumond, D.E., 1981. Archaeology of the Alaska Peninsula: The Naknek Region, 1960-1975. University of Oregon Anthropological Papers, No. 21, University of Oregon, Eugene.

Dumond, D.E., 1984a. Prehistory of the Bering Sea Region. In: Damas D. (Ed.), Arctic, Handbook of North American Indians, Volume 5. Smithsonian Institution Press, Washington, pp. 94-105.

Dumond, D.E., 1984b. Prehistory: Summary. In: Damas, D (Ed.), Arctic, Handbook of North American Indians, Volume 5. Smithsonian Institution Press, Washington, pp. 72-79.

Dumond, D.E., 1987a. The Eskimos and Aleuts. 2nd edition. Thames and Hudson, London.

Dumond, D.E., 1987b. Prehistoric Human Occupation in Southwestern Alaska: A Study of Resource Distribution and Site Location. University of Oregon Anthropological Papers 36. Eugene.

Dumond, D.E., 1988. Trends and Traditions in Alaskan Prehistory: A New Look at an Old View of the Neo Eskimo. In: Shaw, R.D., Harritt, R.K., and Dumond, D.E. (Eds.), The Late Prehistoric Development of Alaska's Native People. Aurora: Alaska Anthropological Association Monograph Series 4, pp. 17-26.

Dumond, D.E., 1994a. The Uyak Site in Prehistory. In: Bray, T.L., Killion, T.W. (Eds.), Reckoning with the Dead: The Larsen Bay Repatriation and the Smithsonian Institution. Smithsonian Institution Press. Washington, pp. 43-53.

Dumond, D.E., 1994b. A reevaluation of late prehistoric houses of the Naknek River region, Southwestern Alaska. Arctic Anthropology 31, 108-118.

Dumond, D.E., 1998. Maritime adaptation on the northern Alaska Peninsula. Arctic Anthropology 35, 187-203.

Dumond, D.E., 2000. The norton tradition. Arctic Anthropology 37, 1-22.

Dumond, D.E., 2001. Western Arctic Small Tool. In: Peregrine, P.N., Ember, M. (Eds.), Encyclopedia of Prehistory Volume 2, Arctic and Subarctic. Kluwer Academic/Plenum Publishers, New York, pp.213-224.

Dumond, D.E., 2003. The Leader Creek Site and its Context. University of Oregon Anthropological Papers 60.

Dumond, D.E., 2004. Volcanism and history on the northern Alaska Peninsula. Arctic Anthropology 41, 112-125.

Dumond, D.E., 2005. Naknek Chronicle: Ten Thousand Years in a Land of Lakes and Rivers and Mountains of Fire. Anchorage: U.S. Department of the Interior: Katmai National Park and Preserve.

Dumond, D.E., Bland, R.L., 1995. Holocene prehistory of the northernmost North Pacific. Journal of World Prehistory 9, 401-450.

Dyson-Hudson, R., Smith, E.A., 1978. Human territoriality: An ecological reassessment. American Anthropologist 80, 21-41.

Eastoe, J.E., 1956. The amino acid composition of fish collagen and gelatin. Biosynthesis of Fatty Acids 65, 363-368.

Eastoe, J.E., 1967. Composition of collagen and allied proteins. In: Ramachandran, G.N. (Ed.),Treatise on collagen, volume I: Chemistry of Collagen. Academic Press, New York, pp. 1-72.

Eerkens, J.W., Bettinger, R.L., 2001. Techniques for assessing standardization in artifact assemblages: Can we scale material variability? American Antiquity 66, 493-504.

Efremov, J.A., 1940. Taphonomy: New branch of paleontology. Pan-American Geologist 74, 81-93.

Eicher, G.J., Jr., Rounsefell, G.A., 1957. Effects of Lake Fertilization by Volcanic Activity on Abundance of Salmon. Limnology and Oceanography 2, 70-76.

Enghoff, I.B., 1983. Size distribution of cod (*Gadus morhua L.*) and Whiting (*Merlangus merlangus* L) (Pisces, Gadidae) from a Mesolithic settlement at Vedbaek, North Zealand, Denmark. Videnskabelige Meddeleserfra Dansk Naturhistorisk Forening 144, 83-97.

Erlandson, J.M., Crowell, A., Wooley, C., Haggarty, J., 1992. Spatial and temporal patterns in Alutiiq paleodemography. Arctic Anthropology 29, 42-62.

Finney, BP, Gregory-Eaves, I, Douglas, M.S.V., Smol, J.P., 2002. Fisheries productivity in the northeastern Pacific Ocean over the past 2,200 years. Nature 416, 729-733.

Fish and Wildlife Service (FWS), 1987. Kodiak National Wildlife Refuge Draft Comprehensive Conservation Plan, Wilderness Review and Environmental Impact Statement. Fish and Wildlife Service, Anchorage, Alaska.

Fitzhugh, J.B., 1996. The Evolution of Complex Hunter-Gatherers in the North Pacific: An Archaeological Case Study from Kodiak Island, Alaska. Ph.D. Dissertation, Department of Anthropology, University of Michigan, Ann Arbor.

Fitzhugh, J.B., 2001. Risk and invention in human technological evolution. Journal of Anthropological Archaeology 20, 125-167.

Fitzhugh, J.B., 2002. Residential and Logistical Strategies in the Evolution of Complex Hunter Gatherers on the Kodiak Archipelago. In: Fitzhugh, J.B., Habu, J. (Eds.), Beyond Foraging and Collecting: Evolutionary Change in Hunter-Gatherer Settlement Systems. Kluwer Academic/Plenum Publishers, New York, pp. 257-304.

Fitzhugh, J.B., 2003. The Evolution of Complex Hunter-Gatherers: Archaeological Evidence from the North Pacific. Kluwer Academic/Plenum Publishers, New York.

Fitzhugh, J.B., 2004. Colonizing the Kodiak Archipelago: Trends in raw material use and lithic technologies at the Tanginak Spring site. Arctic Anthropology 41, 14-40.

Fleming, W.R., 1967. Calcium metabolism of Teleosts. American Zoologists 7, 835-842.

Fogg, G.E., Stewart, W.D., Fay, P., Walsby, A.E., 1973. The Blue-Green Algae. Academic Press, New York.

Ford, P.J., 1992. Interpreting the Grain Size Distributions of Archaeological Shell. In: Stein, J.K. (Ed.), Deciphering a Shell Midden. Academic Press, San Diego, pp. 283-325.

Foster, N.R., 2003. Shellfish Remains from the Mink Island Site (XMK-030), Katmai National Park, Alaska. Report Submitted to Jeanne Schaaf, Lake Clark Katmai Studies Center, Anchorage.

Foucher, R.P., Fournier, D., 1982. Derivation of Pacific cod age composition using length frequency analysis. North American Journal of Fisheries Management 2, 276-284.

Fry, B., 1988. Food web structure on Georges Bank from stable C, N, and S isotopic compositions. Limnology and Oceanography. 33, 1182-1190.

Fry, B., Sherr, E., 1984. $\delta^{13}C$ measurements as Indicators of carbon Flow in marine and freshwater ecosystems. Contributions in Marine Science 27, 13-47.

Garland, A.N., Janaway, R.C., Roberts, C.A., 1988. A study of the decay processes of human skeletal remains from the parish church of the holy trinity, Rothwell, Northhamptonshire, Oxford. Journal of Archaeology 7, 235-252.

Giddings, J.L., 1964. The Archaeology of Cape Denbigh. Brown University Press, Providence.

Giddings, J.L., Anderson, D.D., 1986. Eskimo and Pre-Eskimo Settlements around Kotzebue Sound, Alaska. National Park Service Publications in Archaeology No. 20. Washington: U.S. Department of the Interior.

Gifford, D.P., 1981. Taphonomy and paleoecology: A critical review of archaeology's sister disciplines. Advances in Archaeological Method and Theory 4, 365-438.

Gifford, D.P., Isaac, G.L., Nelson, C.M., 1980. Evidence for predation and pastoralism at prolonged drift: A pastoral Neolithic site in Kenya. Azania 15, 57-108.

Gifford-Gonzalez, D.P.,1991. Bones are not enough: Analogues, knowledge, and interpretive strategies in zooarchaeology. Journal of Anthropological Archaeology 10, 215-254.

Gilbert, A.S., Singer, B.H., 1982. Reassessing zooarchaeological quantification. World Archaeology 14, 21-40.

Gilbert, R., 1977. Applications of Trace Element Research to Problems in Archaeology. In: Blakely, R.L. (Ed.), Biocultural Adaptation in Prehistoric America. University of Georgia Press, Athens, pp. 85-100.

Gillespie, R., 1989. Fundamentals of bone degradation chemistry: Collagen is not "the way". Radiocarbon 31, 239-246.

Gilpin, L.M., 1995. Holocene Paleoseismicity and Coastal Tectonics of Kodiak Islands, Alaska. Ph.D. Dissertation, University of California, Santa Cruz, CA.

Gordon, C.C., Buikstra, J.E., 1981. Soil pH, bone preservation, and sampling bias at mortuary sites. American Antiquity 46, 566-571.

Gordon, E.A., 1993. Screen size and differential faunal recovery: A Hawaiian example. Journal of Field Archaeology 20, 453-459.

Grayson, D.K., 1973. On the methodology of faunal analysis. American Antiquity 38, 432-439.

Grayson, D.K., 1978. Minimum numbers and sample size in vertebrate faunal analysis. American Antiquity 43, 53-65.

Grayson, D.K., 1982. Toward a History of Great Basin Mammals During the Past 15,000 Years. In: Madsen, D.B., O'Connell, J.F. (Eds.), Man and Environment in the Great Basin. Society for American Archaeology Papers 2, pp. 82-101.

Grayson, D.K., 1984. Quantitative Zooarchaeology: Topics in the analysis of Archaeological Faunas. Academic Press, Orlando, Florida.

Grayson, D.K., 2001. The archaeological record of human impacts on animal populations. Journal of World Prehistory 15, 1-68.

Grayson, D.K., Cannon, M.D., 1999. Human Paleoecology and Foraging Theory in the Great Basin. In: Beck, C. (Ed.), Models for the Millennium: The Current Status of Great Basin Anthropological Research. University of Utah Press, Salt Lake City.

Grayson, D.K., Delpech, F., Rigaud, J-P. , Simek, J.F., 2001. Explaining the development of dietary dominance by a single ungulate taxon at Grotte XVI, Dordogne, France. Journal of Archaeological Science 28, 115-125.

Griggs, R.F., 1918. The recovery of vegetation at Kodiak. In scientific results of the Katmai Expeditions of the National Geographic Society. Ohio Journal of Science 19, 1-57.

Griggs, R.F., 1922. The Valley of Ten Thousand Smokes. The National Geographic Society, Washington, D.C.

Griggs, R.F., 1934. The edge of the forest in Alaska and the reasons for its position. Ecology 15, 80-96.

Grupe, G., 1995. Preservation of collagen in bone from dry, sandy soil. American Journal of Physical Anthropology 22,193-199.

Grupe, G., Pipenbrink, H. (Eds.), 1988. Trace Element Contamination in Excavated Bones by Microorganisms. In Trace Elements in Environmental History. Springer-Verlag, Berlin, pp. 103-112.

Gudmundsson, M., 2002. Rheological properties of fish gelatins. Journal of Food Science 67, 2172-2176.

Hackett, C.J., 1981. Microscopic focal destruction (tunnels)-in exhumed human bones. Medicine, Science and the Law 21, 243-265.

Haggarty, J.C., Wooley, C.B., Erlandson, J.M., Crowell, A., 1991. The 1990 Exxon Cultural Resource Program: site Protection and Maritime Cultural Ecology in Prince William Sound and the Gulf of Alaska. Exxon Shipping Company and Exxon Company: Anchorage.

Hales, L.S., Jr., Reitz, E.J., 1992. Historical changes in age and growth of Atlantic croaker, *Micropogonias undulates* (Perciformes: Sciaenidae). Journal of Archaeological Science 19, 73-99.

Hall, B.K, 2005. Bones and Cartilage: Developmental and Evolutionary Skeletal Biology. Elsevier Academic Press, Amsterdam.

Ham, L.C., 1976. Analysis of Shell Samples from Glenrose. In: Matson, R.G. (Ed.), The Glenrose Cannery Sites. Archaeological Survey of Canada No. 52. National Museum of Man, pp. 42-78.

Hames, R.B., Vickers, W.T., 1982. Optimal diet breadth theory as a model to explain variability in Amazonian hunting. American Ethnologist 9, 358-378.

Hamilton T.D., Reed, K.M., Thorson, R.M., 1986. Glaciation in Alaska: Introduction and Overview. In: Hamilton, T.D., Reed, K.M., Thorson, R.M. (Eds.), Glaciation in Alaska: The Geologic Record. Alaska Geological Society, Anchorage, AK.

Hamilton, T.D., Thorson, R.M., 1983. The Cordilleran Ice Sheet in Alaska. In: Porter, S.C. (Ed.), Late Quaternary Environments of the Unites States Volume 1, pp. 38-52.

Hanson, D.B., Buikstra, J.E., 1987. Histomorphological alteration in buried human bone from the Lower Illinois Valley: Implications for palaeodietary research. Journal of Archaeological Science 14, 549-563.

Harris, A.G., Tuttle, E., Tuttle, S., 1995. Geology of National Parks. Kendall/Hunt Publishing Company, Dubuque.

Harritt, R.K., 1988. The Late Prehistory of Brooks River, Alaska. University of Oregon Anthropological Papers 38.

Hausler-Knecht, P., 1991. An Expanded View of the Ocean Bay Period: Preliminary Findings from the KOD-363 Site. Paper Presented, 18th Annual Meeting of the Alaska Anthropological Association, Anchorage (cited in Haggarty *et al.* 1991).

Hausler-Knecht, P., 1993. Early Prehistory of the Kodiak Archipelago. Paper Presented at NSF JSPS Seminar The Origins, Development, and Spread of North Pacific-Bering Sea Maritime Cultures, Honolulu, HI.

Hawkes, K., Hill, K., O'Connell, J.F., 1982. Why hunters gather: Optimal foraging and the Aché of Eastern Paraguay. American Ethnologist 9, 379-398.

Hawkes, K., 1993. Why hunter-gatherers work: An ancient version of the problem of public goods. Current Anthropology 34, 341-361.

Haynes, G., 1980. Evidence of carnivore gnawing on Pleistocene and recent mammalian bones. Paleobiology 6, 341-351.

Haynes, G., 1991. Mammoths, Mastodonts, and Elephants: Biology, Behavior, and the Fossil Record. Cambridge University Press, Cambridge.

Hedges, R.E.M., 2002. Bone diagenesis: An overview of processes. Archaeometry 44, 319-328.

Hedges, R.E.M., 2003. On bone collagen-apatite-carbonate isotopic relationships. International Journal of Osteoarchaeology 13, 66-79.

Hedges, R.E.M., Millard, A.R., 1995. Bones and groundwater: Towards the modeling of diagenetic processes. Journal of Archaeological Science 22, 155-164.

Hedges, R.E.M., Stevens, R.E., Richards, M.P., 2004. Bone as a stable isotope archive for local climatic information. Quaternary Science Reviews 23, 959-965.

Heizer, R.F., 1956. Archaeology of the Uyak Site, Kodiak Island, Alaska. Anthropological Records 17. University of California Press, Berkeley.

Henn, W., 1978.Archaeology on the Alaska Peninsula: The Ugashik Drainage, 1973-1975. Anthropological Papers of the University of Oregon 14. Eugene

Henning, R.A., Loken, M., Olds, B., Morgan, L. (eds.), 1978. Alaska Whales and Whaling. Alaska Geographic Vol. 5, No. 4.

Herring, G.M., 1972. The organic Matrix of Bone. In: Bourne, G. (Ed.), The Biochemistry of Physiology of Bone. Academic Press, New York, pp.128-184.

Heusser, C.J., 1960. Late-Pleistocene Environments of North Pacific North America. Special Publication No. 35. American Geographical Society, New York.

Heusser, C.J., 1985. Quaternary Pollen Records from the Pacific Northwest Coast: Aleutians to the Oregon-California Boundary. In: Bryant, V.M., Holloway, R.G. (Eds.), Pollen Records of Late Quaternary North American Sediments. American Association of Stratigraphic Palynologists Foundation, Dallas, pp. 141-165.

Heusser, C.J., Heusser, L.E., Peteet, D.M., 1985. Late-Quaternary climatic change on the American North Pacific Coast. Nature 315, 482-185.

Higham, T.F.G., Horn, P.L., 2000. Seasonal dating using fish otoliths: Results from the Shag River Mouth site, New Zealand. Journal of Archaeological Science, 27, 4349-448.

Hildebrand, M., 1974. Analysis of Vertebrate Structure. Wiley, New York.

Hildebrandt, W.R., McGuire, K.R., 2002. The ascendance of hunting during the California Middle Archaic: An evolutionary perspective. American Antiquity 67, 231-256.

Hill, A., 1979. Disarticulation and scattering of mammal skeletons. Paleobiology 5, 261-274.

Hill, K., Kaplan, H, Hawkes, K., Hurtado, A., 1987. Foraging decisions among Aché hunter gatherers: Newdata and implications for optimal foraging models. Ethology and Sociobiology 8, 1-36.

Hilton, M.R., 1998. Summary Report of the 1996 Katmai Coastal Archaeological Site Protection Project. With contributions by Richard Bland. Katmai National Park and Preserve, Cultural Resources Program, Anchorage.

Hilton, M.R., 2000. Mink Island Upper Midden Report. Unpublished Report Submitted to Jeanne Schaaf, Lake Clark Katmai Studies Center, Anchorage.

Hilton, M.R., 2002. Evaluating Site Formation Processes at a Higher Resolution: An Archaeological Case Study in Alaska Using Micromorphology and Experimental Techniques. Unpublished Ph.D. dissertation, Department of Anthropology, University of California, Los Angeles.

Hoffman, B.W., Czederpiltz, J.M.C., Partlow, M.A., 2000. Heads or tails: The zooarchaeology of Aleut salmon storage on Unimak Island, Alaska. Journal of Archaeological Science 27, 699-708.

Hole, F.D., 1961. A classification of pedoturbations and some other processes and factors of soil formation in relation to isotrophism and anistropism. Soil Science 91, 375-377.

Holliday, V.T., 1990. Pedology in Archaeology. In: Lasca, N.P., Donahue, J. (Eds.), Archaeological Geology of North America. Centennial Special Volume 4. Geological Society of America, Boulder, pp. 525-540.

Holmberg, H.J., 1985. Holmberg's Ethnographic Sketches. Jaensch, F. (Translation), Falk, M.W. (Ed.). The Rasmussen Library Historical Translation Series, Vol. a. The University of Alaska Press, Fairbanks.

Holmes, C.D., Dale, R.J., McMahan, J.D., 1989. Archaeological Mitigation of the Thorne River Site (CRG177). Office of History and Archaeology, Report Number 15. Division of Parks and Outdoor Recreation, Alaska Department of Natural Resources.

Holtzman, R.C., 1979. Maximum likelihood estimation of fossil assemblage composition. Paleobiology 5, 77-89.

Hood, D.W., 1986. Physical Setting and Scientific History. In: Hood, D.W., Zimmerman, S.T. (Eds.), The Gulf of Alaska: Physical Environment and Biological Resources. National Oceanic and Atmospheric Administration (U.S. Dept. of Commerce) and Minerals Management Service (U.S. Dept. of Interior), Washington, D.C., pp. 5-27.

Hood, R., in prep. Early Kachemak Fish Exploitation at Little Takli Island, Amalik Bay, Alaska: Size Estimates and Taxonomic Distribution. MA Thesis, University of Alaska, Anchorage.

Hrdlicka, A., 1933. Anthropological Explorations on Kodiak Island, Alaska. Explorations and Field-Work of the Smithsonian Institution in 1932, Washington, pp. 41-44.

Hrdlicka, A., 1935. Archaeological Excavations on Kodiak Island, Alaska. Exploration and Field Work of the Smithsonian Institution in 1934. Washington, pp. 47-52.

Hrdlicka, A., 1936. Archaeological Expedition to Kodiak Island, Alaska. Explorations and Field Work of the Smithsonian Institution in 1935. Washington, pp. 47-53.

Hrdlicka, A., 1937. Archaeological Explorations on Kodiak and the Aleutian Islands. Explorations and Field-Work of the Smithsonian Institution in 1936.Washington, pp. 57-62.

Hrdlicka, A., 1944. The Anthropology of Kodiak Island. The Wistar Institute of Anatomy and Biology, Philadelphia.

Hu, Y., Ambrose, S.H., Wang, C., 2006. Stable isotope analysis of human bones from Jiahu Site, Henan, China: Implications for the transition to agriculture. Journal of Archaeological Science 33, 1319-1330.

Hunt, G.L. Jr., Eppley, Z., Drury, W.H., 1981. Breeding Distribution and Reproductive Biology of Marine Birds in the Eastern Bering Sea. In: Hood, D.W, Calder, J.A. (Eds.), The Eastern Bering Sea Shelf: Oceanography and Resources, Volume 2. United States Department of Commerce, U.S. Department of the Interior, Unites States Government Printing Office, Washington, pp. 649-687.

Hurtado, A.M., Hawkes, D, Hill, K., Kaplan, H., 1985. Female subsistence strategies among the Aché of eastern Paraguay. Human Ecology 13, 1-28.

Hussey, J.A., 1971. Embattled Katmai: A History of the Katmai National Monument. Historic Resource Study of the Office of History and Historic Architecture, Western Service Center, National Park Service, San Francisco.

Ingram, R.T., Clarke, B.L., Fischer, L.W., Fitzpatrick, L.A., 1993. Distribution of noncollagenous proteins in the matrix of adult human bone: Evidence of anatomic and functional heterogeneity. Journal of Bone and Mineral Research 8, 1019-1029.

Iverson, B.K., in prep, A 2000-year View of Human-Avian Interaction: A Case Study from Coastal Alaska. Masters Thesis, University of Alaska Fairbanks.

Jackson, J.B.C., Kirby, M.X., Berger, W.H., Bjorndal, K.A., Botsford, L.W., Bourque, B.J., Bradbury, R.H., Cook, R., Erlandson, J., Estes, J.A., Hughes, T.P., Kidwell, S., Lange, C.B., Lenihan, H.S., Pandolfi, J.M., Peterson, C.H., Steneck, R.S., Tegner, M.J., and Warner, R.W., 2001. Historical overfishing and the recent collapse of coastal ecosystems. Science 293, 629-638.

Jackson, S.A., Cartwright, A.G., Lewis, D., 1978. The morphology of bone mineral crystals. Calcified Tissue International 25, 217-222.

Jacob, K.H., 1986. Seismicity, Tectonics, and Geohazards of the Gulf of Alaska Regions. In: Hood, D.W., Zimmerman, S.T. (Eds.), The Gulf of Alaska: Physical environment and Biological Resources. National Oceanic and Atmospheric Administration (W.S. Department of Commerce)and Minerals Management Service (U.S. Department of Interior), Washington, D.C., pp. 145-184.

Janaway, R.F., 1987. The Preservation of Organic Materials in Association with Metal Artifacts Deposited in Inhumation Graves. In: Boddington, Garland, Janaway (Eds.), Death, Decay, and Reconstruction: Approaches to Archaeology and forensic Science. Manchester University Press, Manchester, pp. 127-148.

Jans, M.M.E., Nielsen-Marsh, C.M., Smith, C.I., Collins, M.J., Kars, H., 2004. Characterization of microbial attack on archaeological bone. Journal of Archaeological Science 31, 87-95.

Jenkins, G.N., 1978. Chemical Composition of Teeth. In: Jenkins, J.N., Edgar, W.M. (Eds.), The Physiology and Biochemistry of the Mouth, 4th ed. Blackwell, Oxford.

Johnson, E., 1985. Current Developments in Bone Technology. In: Schiffer, M.B. (Ed.), Advances in Archaeological Method and Theory, vol. 8. Academic Press, New York, pp. 157-235.

Johnson, E., 1989. Human Modified Bones from Early Southern Plains Sites. In: Bonnichesen, R., Sorg, M.H. (Eds.), Bone Modification .University of Maine Center for the Study of the First Americans, Orono, pp. 431-471.

Johnson, L.L., Winslow, M.A., 1991. Paleoshorelines and Prehistoric Settlements on Simeonof and Chernabura Islands, Outer Shumagin Islands, Alaska. In: Johnson, L.L. (Ed.), Paleoshorelines and Prehistory: An Investigation of Method. CRC Press, Boca Raton, pp. 171-186.

Joint Federal-State Land Use Planning Commission for Alaska (LUPCA), 1973. Major Ecosystems of Alaska (map). U.S. Geological Survey, Fairbanks.

Jones, A.K.G., 1982. Bulk-sieving and the recovery of fish remains from urban archaeological sites. Environmental Archaeology in the Urban Context 2, 79-85.

Jones, A.K.G., 1986. Fish Bone Survival in the Digestive Systems of the Pig, Dog and Man: Some Experiments. In: Brinkhuizen, D.C., Clason, A.T. (Eds.), Fish and Archaeology. British Archaeological Reports International Series, No. 294, Oxford, pp. 53-61.

Jordan, J.W., 2000. Coastal paleogeography and human occupation of the western Alaska Peninsula. Geoarchaeology 15, 4.

Jordan, R.H., Knecht, R.A., 1988. Archaeological Research on Western Kodiak Island, Alaska: The Development of Koniag Culture. In: Shaw, R.D., Harritt, R.K., Dumond, D.E. (Eds.), Late Prehistoric Development of Alaska's Native People. Aurora IV, Alaska Anthropological Association, Anchorage.

Jordan, J.W., Krumhardt, A., 2003. Postglacial climate and vegetation of the western Alaska Peninsula. Alaska Journal of Anthropology 1, 16-33

Jordan, J.W., Maschner, H.D.G., 2000. Coastal paleogeography and human occupation of the Western Alaska Peninsula. Geoarchaeology 15, 385-414.

Kaplan, H., Hill, K., 1992. The Evolutionary Ecology of Food Acquisition. In: Smith, E.A., Winterhalder, B. (Eds.), Evolutionary Ecology and Human Behavior. Aldine, Chicago, pp. 167-201.

Karlstrom, T.N.V., 1969. Regional Setting and Geology. In: Karlstrom, T.N.V., Ball, G.E. (Eds.), The Kodiak Island Refugium: Its Geology, Flora, Fauna and History. The Boreal Institute, University of Alberta, Calgary, pp. 20-54.

Katzenberg, M.A., 2000. Stable Isotope Analysis: A Tool for Studying Past Diet, Demography, and Life History. In: Katzenberg, M.A., Saunders, S.R. (Eds.), Biological anthropology of the Human Skeleton. Wiley-Liss, Inc., New York, pp. 305-327.

Kaufman, D.S. , Ager, T.A., Anderson, N.J., Anderson, P.M., Andrews, J.T., Bartlein, P.J., Brubaker, L.B., Coats, L.L., Cwynar, L.C., Duvall, M.L., Dyke, A.S., Edwards, M.E., Eisner, W.R., Gajewski, K., Geirsdottir, A., Hu, F.S., Jennings, A.E., Kaplan, M.R., Kerwin, M.W., Lozhkin, A.V., MacDonald, G.M., Miller, G.H., Mock, C.J., Oswald, W.W., Otto-Bliesner, B.L., Porinchu, D.F., Ruhland, K., Smol, J.P., Steig, E.J., Wolfe, B.B., 2004. Holocene thermal maximum in the western Arctic (0-180 W). Quaternary Science Reviews 23, 529–560

Keeley, L.H., 1988. Hunter-gatherer economic complexity and "population pressure": A cross-cultural analysis. Journal of Anthropological Archaeology 7, 373-411.

Keller, S.A., Reiser, H.N., 1959. Geology of the Mount Katmai Area, Alaska. U.S. Geological Survey Bulletin 1058-G, Washington, D.C.

Kelly, R.L., 1995. The Foraging Spectrum: Diversity in Hunter-Gatherer Fishing Strategies. Smithsonian Institution Press, Washington, D.C.

Kennedy, B.V.E., 1988. Variation in $\delta^{13}C$ Values of Post-Medieval Europeans, Ph.D. Dissertation, University of Calgary.

Kent, S., 1993. Variability in faunal assemblages: The influence of hunting skill, sharing, dogs, and mode of cooking on faunal remains at a sedentary Kalahari community. Journal of AnthropologicalArchaeology 12, 323-85.

Kessler, D.W., 1985. Alaska's Saltwater Fishes and Other Sea Life. Alaska Northwest Publishing Co., Anchorage.

Kim, H.-M., Rey, C., Glimcher, M.J., 1995. Isolation of calcium-phosphate crystals of bone by nonaqueous methods at low temperature. Journal of Bone and Mineral Research 10, 1589-1601.

Kizely, I., 1973. Derivatographic examination of subfossil and fossil bones. Current Anthropology 14. 280-286.

Klein, R.G., Cruz-Uribe, K., 1984. The Analysis of Animal Bones from Archaeological Sites. University of Chicago Press, Chicago.

Knecht, R.A., 1995. The Late Prehistory of the Alutiiq People: Culture Change on the Kodiak Archipelago from 1200-1750 AD. PhD. Dissertation, Department of Anthropology, Bryn Mawr College, Bryn Mawr, Pennsylvania.

Knecht, R.A., Davis, R.S., Carver, G.A., 2001. The Margaret Bay Site and Eastern Aleutian Prehistory. In: Dumond, D.E. (Ed.), Archaeology in the Aleut Zone of Alaska: Some Recent Research. University of Oregon Anthropological Papers, 58, Department of Anthropology and the Museum of Natural History, University of Oregon, Eugene, pp. 35-69.

Knight, J.A., 1985. Differential Preservation of Calcined Bone at the Hirundo Site, Alton, Maine. University of Main Press, Orono.

Kopperl, R.E., 2001. Herring use in southern Puget Sound: Analysis of fish remains at 45-KI-437. Northwest Anthropological Research Notes 35, 1-20.

Kopperl, R.E., 2003. Cultural Complexity and Resource Intensification on Kodiak Island, Alaska. PhD. Dissertation, University of Washington, Seattle.

Kramer, D.E., O'Connell, V.M., 1995. Guide to Northeast Pacific Rockfishes. Marine Advisory Bulletin 25. Alaska Sea Grant, Fairbanks.

Kramer, D.E., Barss, W.H., Paust, B.C., Bracken, B.E., 1995. Guide to Northeast Pacific Flatfishes. Marine Advisory Bulletin 47, Alaska Sea Grant, Fairbanks.

Krantz, G.S., 1968. New method of counting mammal bones. American Journal of Archaeology 72, 286-288.

Lambert, J.B., Simpson, S.V., Weiner, S.G., Buikstra, J.E., 1985. Induced metal-ion exchange in excavated human bone. Journal of Archaeological Science 12, 85-92.

Larsen, H., Rainey, F., 1948. Ipiutak and the Arctic Whale Hunting Culture. Anthropological Papers of the American Museum of National History 42.

Laybolt, A.D., 2002. The Micromorphology of Midden Sediments at Mink Island (XMK-030) Employing Thin Sections and Latex Peels for Environmental Reconstruction. Poster presented at the 53rd Arctic Science Conference, American Association for the Advancement of Science, Arctic Division. September 18-21, University of Alaska, Fairbanks.

Leach, B.F., 1979. Fish and crayfish from the Washpool Midden site, New Zealand: Their use in determining season of occupation and prehistoric fishing methods. Journal of Archaeological Science 6, 109-126.

Leach, F., Davidson, J., 2000. Pre-European catches of snapper (*Pagrus auratus*) in northern New Zealand. Journal of Archaeological Science 27, 509-522.

Lee, D.D., Glimcher, M.J., 1991. Three-dimensional spatial relationship between collagen fibrils and the inorganic calcium phosphate crystals of pickerel (*Americanus americanus*) and herring (*Clupea harengus*) bone. Journal of Molecular Biology 217, 487-501.

Lee-Thorp, J.A., 1989. Stable Carbon Isotopes in Deep Time: The Diets of Fossil Fauna and Hominids. Ph.D. Thesis, University of Cape Town, Cape Town.

Levitan, B., 1982. Excavations at West Hill Uley: the Sieving and Sampling Programme. Western Archaeological Trust, Gloucester.

Liden, K., Takahashi, C., Nelson, D.E., 1995. The effects of NaOH treatment on the composition of extracted bone collagen. Journal of Archaeological Science 22, 321-326.

Lindsay, W.L., 1979. Chemical Equilibria in Soils. John Wiley and Sons, New York.

Linse, A.R., 1992. Is Bone Safe in a Shell Midden? In: Stein, J.K. (Ed.), Deciphering a Shell Midden. Academic Press, San Diego, pp. 327-345.

Lisianskii, U., 1814. Voyage Round the World in the Years 1803, 1804, 1805, and 1806. Bibliotheca Australiana 42. N. Israel, Amsterdam and De Capo Press, New York.

Longin, R., 1971. New method of collagen extraction for radiocarbon dating. Nature 230, 241-242.

Loring, S., Prokopec, M., 1994. A Most Peculiar Man: The Life and Times of Ales Hrdlicka. In: Bray, T.L, Killion, T.W. (Eds.), Reckoning with the Dead: The Larsen Bay Repatriation and the Smithsonian Institution. Smithsonian Institution Press, Washington D.C., pp. 26-40.

Love, M.S., Yoklavich, M., Thorsteinson, L., 2002. The Rockfishes of the Northeast Pacific. University of California Press, Berkeley.

Luebbers, R., 1978. Excavations: Stratigraphy and Artifacts. In: Hester, J.J., Nelson, S.M. (Eds.), Studies in Bella Bella Prehistory, vol. 5. Department of Archaeology Simon Fraser University, Burnaby, pp.11-66.

Lyman, R.L., 1982. Archaeofaunas and Subsistence Studies. In: Schiffer, M.B. (Ed.), Advances in Archaeological Method and Theory, vol. 5. Academic Press, New York, pp. 331-393.

Lyman, R.L, 1984. Bone density and differential survivorship in fossil classes. Journal of Anthropological Archaeology 2, 259-299.

Lyman, R.L., 1994. Vertebrate Taphonomy. Cambridge University Press, Cambridge.

Lyman, R.L., 2008. Quantitative Paleozoology. Cambridge University Press, New York.

Lyman, R.L., O'Brien, M.J., 1987. Plow-zone zooarchaeology: Fragmentation and identifiability. Journal of Field Archaeology 14, 493-498.

Lyman, R.L., Houghton, L.E., Chambers, A.L., 1992. The effect of structural density on marmot skeletal part representation in archaeological sites. Journal of Archaeological Science 19, 557-573.

Lynch, J.M., Poole, N.J., 1979. Microbial Ecology, A Conceptual Approach. Blackwell, Oxford.

MacArthur, R.H., Pianka, E.R., 1966. On optimal use of a patchy environment. American Naturalist 95,195-199.

Madsen, D.B., Schmitt, D.N., 1998. Mass collecting and the diet breadth model: A great basin example. Journal of Archaeological Science 25, 445-455.

Maguire, J.M., Pemberton, D., Collett, M.H., 1980. The Makapansgat Limeworks Grey Breccia: Hominids, hyaenas, hystricids or hillwash? Paleontologia Africana 23, 75-98.

Mann, D.H., Hamilton, T.D., 1995. Late Pleistocene and Holocene paleoenvironments of the North Pacific Coast. Quaternary Science Reviews 14, 449-471.

Mann, D.H., Crowell, A.L., Hamilton, T.D., Finney, BP, 1998. Holocene geologic and climatic history around the Gulf of Alaska. Arctic Anthropology 35, 112-131.

Mann, M., 2003. Little Ice Age. In: MacCracken, M.C., Perry, J.S. (Eds.), Encyclopedia of Global Environmental Change, Volume 1, The Earth System: Physical and Chemical Dimensions of Global Environmental Change. John Wiley & Sons. Retrieved 17 November 2012.

Marchiafava, V., Bonucci, E., Ascenzi, A., 1974. Fungal osteoclasia: A model of dead bone resorption. Calcified Tissue Research 14, 195-210.

Marean, C.W., 1991. Measuring the post-depositional destruction of bone in archaeological assemblages. Journal of Archaeological Science 18, 677-694.

Marean, C.W., Spencer, L.M., 1991. Impact of carnivore ravaging on zooarchaeological measures of element abundance. American Antiquity 56, 645-58.

Marean, C.W.,Abe, Y., Nilssen, P.J., Stone, E.C., 2001. Estimating the minimum number of skeletal elements (MNE) in zooarchaeology: A review and a new image-analysis GIS approach. American Antiquity 66, 333-348.

Martill, D.M., 1991. Bones as Stones: The Contribution of Vertebrate Remains to the Lithologic Record. In: Donovan, S.K. (Ed.), The Process of Fossilization. Columbia University Press, New York, pp. 270-292.

Maschner, H.D.G., 1999. Prologue to the prehistory of the lower Alaska Peninsula. Arctic Anthropology 36, 84-102.

Mason, O.K., Jordan, J.W., 1993. Heightened North Pacific storminess during synchronous Late Holocene erosion of northwest Alaska beach ridges. Quaternary Research 40, 55-69.

Mason, O.K., Hilton, M., Laybolt, D., 2008. Geoarchaeology of the Mink Island Site (XMK 030) Katmai National Monument. Draft report submitted to Jeanne Schaaf, Lake Clark Katmai Studies Center, Anchorage.

Masterson, W., Hurley, H., 2004. Chemistry: Principles and Reactions. Thomson learning, New York.

Matson, R.G., Coupland, G., 1995. The Prehistory of the Northwest Coast. Academic Press, New York.

Maxwell, M.S., 1985. Prehistory of the Eastern Arctic. Academic Press, New York.

McCartney, A.P., Okada, H., Okada, A., Workman, W., 1998. Introduction. In North Pacific and Bering Sea Maritime Societies: The Archaeology of Prehistoric and Early Historic Coastal Peoples. Arctic Anthropology 35 Special Issue.

McCutcheon, P.T., 1992. Burned Archaeological Bone. In: Stein, J.K. (Ed.), Deciphering a Shell Midden. Academic Press, San Diego, pp. 347-371.

McGovern-Wilson, R.J., 1992. The Taphonomy of Big-Game Hunting in Prehistoric New Zealand. PhD. Thesis, University of Otago, Dunedin.

McHugh, W.P., 1962. Archaeological investigations on Kodiak Island. Arctic Anthropology 1, 113-115.

Mecklenburg, C.W., Mecklenburg, T.A., Thosteinson, L.K., 2002. Fishes of Alaska. American Fisheries Society, Bethesda.

Merck, C.H., 1980. Siberia and Northwestern America 1788-1792: The Journal of Carl Heinrich Merck. Materials for the Study of Alaska History, No. 17, Pierce, R.A. (ed.), Jaensch, F. (trans.). Limestone Press, Kingston, Ontario.

Micozzi, M.S., 1991. Postmortem Change in Human and Animal Remains: A Systematic Approach. Charles C. Thomas, Springfield.

Miller, G.J., 1975. A Study of Cuts, Grooves and Other Marks on Recent and Fossil Bone: II, Weathering Cracks, Fractures, Splinters and Other Similar Natural Phenomena. In: Swanson, E. (Ed.), Lithic Technology. Mouton, The Hague, pp. 212-226.

Miller, T.P., Smith, R.L., 1987. Late Quaternary caldera-forming eruptions in the eastern Aleutian Arc, Alaska. Geology 15, 434-438.

Minagawa, M., Wada, E., 1984. Stepwise enrichment of ^{15}N along food chains: Further evidence and the relation between $\delta^{15}N$ and animal age. Geochimica et Cosmochimica, acta. 48, 1135-1140.

Misarti, N., 2007. Six Thousand Years of Change in the Northeast Pacific: An Interdisciplinary View of Maritime Ecosystems. Ph. D. Dissertation, University of Alaska Fairbanks.

Misarti, N., Finney, BP, Maschner, H.D.G., Wooller, M.J., 2009. Changes in northeast Pacific marine ecosystems over the last 4500 years: Evidence from stable isotope analysis of bone collagen from archaeological middens. Holocene 19, 1139-1151.

Mishler, C., 2001. Black Ducks and Salmon Bellies: An Ethnography of Old Harbor and Ouzinkie, Alaska. U.S. Minerals Management Service, Technical Memorandum 7. Alaska Department of Fish and Game, Division of Subsistence, Anchorage.

Misra, D.N., 1984. Surface Chemistry of Bone and Tooth Mineral. In: Dickson, G.R. (Ed.), Methods of Calcified Tissue Preparation. Elsevier, Amsterdam.

Mobley, C.M., Haggarty, J.C., Utermohle, C.J., Eldridge, M., Reanier, R.E., Crowell, A., Ream, B.A., Yesner, D.R., Erlandson, J.M., Buck, P.E., 1990. The EXXON VALDEZ Cultural Resource Program. Exxon Shipping Company and Exxon Company, Anchorage.

Monks, G.G., 1981. Seasonality Studies. In: Schiffer, M.B. (ed.), Advances in archaeological Method and Theory, Vol. 4. Academic Press, New York, pp. 177-240.

Monks, G.G., 1987. Prey as bait: The Deep Bay example. Canadian Journal of Archaeology 11, 119-142.

Morlan, R.E., 1980. Taphonomy and Archaeology in the Upper Pleistocene of the Northern Yukon Territory: A Glimpse of the Peopling of the New World. Archaeological Survey of Canada Paper No. 94. National Museum of Man, Ottawa.

Moss, M.L., 1961. Osteogenesis of acellular teleost fish bone. American Journal of Anatomy 108, 99-109.

Moss, M.L., 1963. The biology of acellular teleost bone. Annuals of the New York Academy of Sciences 109, 337-350.

Moss, M.L., 1984. Phosphate analysis of archaeological sites, Admiralty Island, Southeast Alaska. Syesis 17, 95-100.

Moss, M.L., Erlandson, J.M., 1992. Forts, refuge rocks, and defensive sites: The antiquity of warfare along the North Pacific coast of North America. Arctic Anthropology 29, 73-90.

Moyle, P.B., Cech, J.J., 1996. Fishes: An Introduction to Ichthyology. Prentice Hall, Upper Saddle River.

Muhs, D.R., Thorson, R.M., Clauge, J.J., Matthews, W.H., McDowell, P.F., Kelsey, H.M., 1987. Pacific Coast and Mountain System. In: Graf, W.L. (Ed.), Geomorphic System of North America, Centennial Special Volume 2, The Geological Society of America, pp. 517-581.

Munsell, 1954. Munsell Color Company, Inc. Baltimore, 2.

Murdoch, J., 1988. Ethnological Results of the Point Barrow Expedition. Smithsonian Institution Press, Washington, D.C.

Murray, M.S., 2004a. Progress Report on the Mink Island Archaeofaunal Analysis. Report on file, Lake Clark/Katmai US National Park Service, Anchorage.

Murray, M.S., 2004b. Second Progress Report on the Mink Island Archaeofaunal Analysis, Report on file, Lake Clark/Katmai US National Park Service, Anchorage

Myers, R.A., Worm, B., 2003. Rapid worldwide depletion of predatory fish communities. Nature 423, 280-283.

National Park Service, 1968. Report of Katmai Coast Sea Mammal Survey. Report on File at Lake Clark-Katmai Studies Center, National Park Service, Anchorage, Alaska.

National Science Foundation, 1998. Arctic Research of the Unites States, Spring/Summer 1998. Electronic Document, http://www.nsf.gov/pubs/1998/nsf98150/nps.htm, accessed January 2, 2011.

National Science Foundation, 2002. Arctic Research of the United States Vol. 16 (Spring/Summer 2002): 40-41. Published for the Interagency Arctic Research Commission by the National Science Foundation, Arlington, VA.

Nelson, D.L, Cox, M.M., 2005. Lehninger Principles of Biochemistry. W.H. Freeman, New York.

Nelson, R.E., Jordan, R.H., 1988. A postglacial pollen record for western Kodiak Island, Alaska. Arctic 41, 59-63.

Neuman, W. Mulryan, B., 1968. The discrepancy in the carbonate found in fish bone and blood. Calcified Tissue International 2, 237-241.

Nichol, R.K., 1982a. Seasonal dating from fish frequencies. Journal of Archaeological Science 9, 391-393.

Nichol, R.K., 1982b. Seasonality from fish remains. N.Z.A.A. Newsletter, 25, 53-64.

Nichol, R.K., Wild, C.J., 1983. Estimation of the original number of individuals from paired bone counts using estimators of the Krantz type. Journal of Field Archaeology 10, 337-344.

Nicholson, R.A., 1992a. An assessment of the value of bone density measurements to archaeoichthyological studies. International Journal of Osteoarchaeology 2, 139-154.

Nicholson, R.A., 1992b. Bone survival: The effects of sedimentary abrasion and trampling on fresh and cooked bone. International Journal of Osteoarchaeology 2, 79-90.

Nicholson, R.A., 1996a.Bone degradation, burial medium and species representation: Debunking myths, an experiment based approach. Journal of Archaeological Science 23, 513-533.

Nicholson, R.A., 1996b. Fish bone diagenesis in different soils. Archaeofauna 5, 79-91.

Nicholson, R.A., 1998. Bone degradation in a compost heap. Journal of Archaeological Science 25, 393-403.

Nielsen-Marsh, C.M., Hedges, R.E.M., 1999. Bone porosity and the use of mercury intrusion porosimetry in bone diagenesis Studies. Archaeometry 41, 165-174.

Nielsen-Marsh, C.M., Hedges, R.E.M., 2000. Patterns of diagenesis in bone I: The effects of site environments. Journal of Archaeological Science 27, 1139-1150.

Noe-Nygaard, N., 1983. The Importance of Aquatic Resources to Mesolithic Man at Inland Sites in Denmark. In: Grigson, C., Clutton-Broch, J. (Eds.), Animals and archaeology: 2. Shell Middens, Fishes and Birds, B.A.R., Oxford, pp. 125-142.

Norris, F.B., 1996. Isolated Paradise: An Administrative History of the Katmai and Aniakchak National Park Units. U.S. Government Printing Office, Washington.

Nowack, M., 1968. Archaeological Dating by Means of Ash Strata, M.A. Thesis, University of Oregon, Eugene.

OCSEAP, 1986. Marine Fishes: Resources and Environments. In: Hood, D.W., Zimmerman, S.T. (Eds.), The Gulf of Alaska: Physical Environmental and Biological Resources. National Oceanic and Atmospheric Administration, Anchorage, pp. 399-415.

Ojaveer, H., MacKenzie, B.R., 2007. Introduction: Historical development of fisheries in northern Europe reconstructing chronology of interactions between nature and man. Fisheries Research 87, 102-105.

Olsen, S.L., Shipman, P., 1988. Surface modification on bone: Trampling versus butchery. Journal of Archaeological Science 15, 535-553.

Orchard, T. J., 2003. An Application of the Linear Regression technique for Determining Length and Weight of Six Fish Taxa: The Role of Selected Fish Species in Aleut Paleodiet. B.A.R. International Series, Oxford, 1172.

Oswalt, W., 1955. Prehistoric sea mammal hunters at Kaflia, Alaska. Anthropological Papers of the University of Alaska 4, 22-61.

Oswalt, W., 1967. Alaskan Eskimos. Chandler, San Francisco.

Parenti, L.R., 1986. The phylogenic significance of bone types in euteleost fishes. Zoological Journal of the Linnean Society 87, 37-51.

Partlow, M.A., 2000. Salmon Intensification and Changing Household Organization in the Kodiak Archipelago. Ph.D. Dissertation. Madison: University of Wisconsin.

Partlow, M.A., 2006. Sampling fish bones: A consideration of the importance of screen size and disposal context in the North Pacific. Arctic Anthropology 43, 67-79.

Partnow, P., 2001. Making History: Alutiiq/Sugpiaq Life on the Alaska Peninsula. University of Alaska Press, Fairbanks.

Pauly, D., 1995. Anecdotes and shifting baseline syndrome of fisheries. TREE 10, 430.

Payne, S., 1972a. On the Interpretation of Bone Samples from Archaeological Sites. In: Higgs, E.S. (Ed.), Papers in economic prehistory. Cambridge University Press, Cambridge, pp.65-82.

Payne, S., 1972b. Partial Recovery and Sample Bias: The Results of Some Sieving Experiments. In: Higgs, E.S. (Ed.), Papers in Economic Prehistory. Cambridge University Press, Cambridge, pp. 49-64.

Person, A., Bocherens,H., Mariotti, A., Renard, M., 1996.Diagenetic evolution and experimental heating of bone phosphate. Palaeogeography, Palaeoclimatoloty, Palaeoecology 126, 135-149.

Petchey, F., Higham, T., 2000. Bone diagenesis and radiocarbon dating of fish bones at the Shag River Mouth site, New Zealand. Journal of Archaeological Science 27, 135-150.

Peteet, D.M., Mann, D.H., 1994. Late-glacial vegetational, tephra, and climatic history of southwestern Kodiak Island, Alaska. Ecoscience 1, 255-267.

Pewe, T.L., 1975. Quaternary Geology of Alaska. Geological Survey Professional Paper 835. U.S. Government Printing Office, Washington D.C.

Pfeiffer, S., Varney, T.L., 2000. Quantifying Histological and Chemical Preservation in Archaeological Bone. In: Ambrose, S.A., Katzenberg, M.A. (Eds.), Biogeochemical Approaches to Paleodietary Analysis. Kluwer, New York, pp. 141-158.

Pflacker, G., 1969. Tectonics of the March 27, Alaska Earthquake. U.S. Geological Survey Professional Paper 541-I.

Pflacker, G., Berg, H.C., 1994a. Introduction. In: Pflacker, G., Berg, H.C. (Eds.), The Geology of Alaska. The Geology of North America Volume G-1, The Geological Society of America, pp. 1-6.

Phleger, C.F., Patton, J., Grimes, P., Lee, R.F., 1976. Fish-bone oil: Percent total Body lipid and carbon-14 uptake following feeding of 1-^{14}C-palmitic acid. Marine Biology 35, 85-89.

Phleger, C.F., Laub, R.J., Benson, A., 1989. Skeletal lipid depletion in spawning salmon. Lipids 24, 286-289.

Phleger, C.F., Laub, R.J., Wambeke, S.R., 1995. Selective skeletal fatty acid depletion in spawning Pacific pink salmon, *Oncorhynchus gorbuscha*. Comparative Biochemistry and Physiology Part B: Biochemistry and Molecular Biology 111, 435-439.

Pinnegar, J.K, Engelhard, G.H., 2008. The 'shifting baseline' phenomenon: A global perspective. Rev. Fish Biol. Fisheries 18, 1-18.

Posner, A.S., 1985. The mineral of bone. Clinical Orthopaedics and Related Research 200, 87-99.

Powers, W.R., Hoffecker, J.F., 1989. Late Pleistocene settlement in the Nenana Valley, Central Alaska. American Antiquity 54, 263-287.

Pullar, G.L., 1992. Introduction. In: Jordan, R.H., de Laguna, F., Steffian, A. (Eds.), Contributions to the Anthropology of Southcentral and Southwestern Alaska. Anthropological Papers of the University of Alaska vol. 24, Fairbanks, pp. 1-2.

Pullar, G.L., 1994. The Qikertarmiut and the Scientist: Fifty Years of Clashing World Views. In: Bray, T.L., Killion, T.W. (Eds.), Reckoning with the Dead: The Larsen Bay Repatriation and the Smithsonian Institution. Smithsonian Institution Press, Washington D.C., pp. 15-25.

Radin, N.S., 1981. Extraction of tissue lipids with a solvent of low toxicity. Methods Enzymol 72, 5-7.

Rausch, R.L., 1953. On the status of some Arctic mammals. Arctic 6, 91-148.

Rausch, R.L., 1969. Origin of the Terrestrial Mammalian Fauna of the Kodiak Archipelago. In: Karlstrom, T.N.V., Ball, G.E. (Eds.), The Kodiak Island Refugium: Its Geology, Flora, Fauna, and History. Boreal Institute, University of Alberta, Edmonton, pp. 216-235.

Reeburgh, W.S., Kipphut, G.W., 1986. Chemical Distributions and Signals in the Gulf of Alaska, its Coastal Margins and Estuaries. In: Hood, D.W., Zimmerman, S.T. (Eds.), The Gulf of Alaska: Physical environment and Biological Resources. National Oceanic and Atmospheric Administration (W.S. Department of Commerce) and Minerals Management Service (U.S. Department of Interior),Washington D.C., pp. 77-92.

Reed, R.K., Schumacher, J.D., 1986. Physical Oceanography. In: Hood, D.W., Zimmerman, S.T. (Eds.), The Gulf of Alaska: Physical environment and Biological Resources. National Oceanic and Atmospheric Administration (W.S. Department of Commerce) and Minerals Management Service (U.S. Department of Interior), Washington D.C., pp. 57-76.

Regenstein, J.M , Zhou, P., 2007. Collagen and Gelatin from Marine By-Products. In: Shahidi, F. (Ed.), Maximising the Value of Marine By-Products. Woodhead Publishing Limited, Cambridge, pp. 279-303.

Reger, D.R., 1977. An Eskimo site near Kenai, Alaska. Anthropological Papers of the University of Alaska 18, 37-52.

Reger, D.R., 1981. A Model for Culture History in Upper Cook Inlet, Alaska. Unpublished Ph.D. Dissertation. Department of Anthropology, Washington State University, Pullman.

Reger, D.R., 1998. Archaeology of the northern Kenai Peninsula and Upper Cook Inlet. Arctic Anthropology 35, 160-171.

Reitz, E.J., Wing, E.S., 1999. Zooarchaeology. Cambridge University Press, Cambridge.

Reynolds, W.W., 1979. Perspective and introduction to the symposium: Thermoregulation in Ecotherms. American Zoology 19, 193-194.

Richter, J., 1986. Experimental study of heat induced morphological changes in fish bone collagen. Journal of Archaeological Science 13, 471-481.

Ricker, W.E., 1973. Linear regressions in fishery research. Journal of the Fisheries Research Board of Canada 30, 409-434.

Riehle, J.R., 2002. The Geology of Katmai National Park and Preserve. Publication Consultants, Anchorage.

Riehle, J.R., Detterman, R.L., Yount, M.E., Miller, J.W., 1993. Geological Map of the Mount Katmai Quadrangle and Adjacent Parts of the Naknek and Afognak Quadrangles, Alaska. Miscellaneous Investigations Series, Map I-2204. United States Geological Survey, Denver.

Riehle, J.R., Dumond, D.E., Meyer, C.E., Schaaf, J.M., 2000. Tephrachronology of the Brooks River Archaeology District, Katmai National Park and Preserve, Alaska. In: McGuire, W.J., Hancock, P.L., Stewards, I.L., (Eds.),The Archaeology of Geological Catastrophes. Geological Society Special Publication 171, London, pp. 245-266.

Riehle, J.R., Waiit, R.B., Meyer, C.E., Calk, L.C., 1998. Age Formation of Kaguyak Caldera, Eastern Aleutian Arc, Alaska, Estimated by Tephrochronology. In: Gray, J.E., Riehle, J.R., (Eds.), Geologic Studies in Alaska by the U.S. Geological Survey, 1996. Geological Survey Professional Paper 1595. U.S. Government Printing Office, Washington, D.C., pp. 161-168.

Ringrose, T.J., 1993. Bone counts and statistics: A critique. Journal of Archaeological Science 20, 121-157.

Robinson, S., Nicholson, R.A., Pollard, A.M., O'Conner, T.P., 2003. An evaluation of nitrogen porosimetry as a technique for predicting taphonomic durability in animal bones. Journal of Archaeological Science 30, 391-403.

Rogers, D.E., Rogers, B.J., Rosenthal, R.J., 1986. The Nearshore Fish. In: Hood, D.W., Zimmerman, D.W. (Eds.), The Gulf of Alaska: Physical Environment and Biological Resources. U.S. Government Printing Office, Washington, D.C., pp. 399-416.

Rojo, A.L., 1986. Live length and weight of cod (*Gadus morhua*) estimated from various skeletal elements. North American Archaeologist 7, 329-351.

Rojo, A.L., 1987. Excavated fish vertebrae as predictors in bioarchaeological research. North American Archaeologist 8, 209-225.

Rojo, A.L., 1991. Dictionary of Evolutionary Fish Osteology. CRC Press, Boca Ratton.

Rolfe, W.E.I., Brett, D.W., 1969. Fossilization Processes. In: Eglington, G., Murphy, M.T.J. (Eds.), Organic Geochemisty: Methods and Results. Springer-Verlag, Berlin, pp. 213-244.

Romer, A.S., Parsons, T.S., 1977. The Vertebrate Body. 5th ed. W.B. Saunders Company, Philadelphia.

Roppel, P., 1982. Alaska's Salmon Hatcheries, Volume 20. Alaska Historical Commission Studies in History, Anchorage.

Roppel, P., 1986. Salmon from Alaska. Alaska Historical Commission Studies in History, Anchorage.

Rosenberg, M., 1998. Cheating at musical chairs: Territoriality and sedentism in an evolutionary context. Current Anthropology 39, 653-682.

Ross, A., Duffy, R., 2000. Fine mesh screening of midden material and the recovery of fish bone: The development of flotation and deflocculation techniques for an efficient and effective procedure. Geoarchaeology: An International Journal. 15, 21-41

Ruff, C.B., Trinkaus, E., Walker, A., Larsen, C.S., 1993. Post cranial robusticity in Homo: Temporal trends and mechanical interpretation. American Journal of Physical Anthropology 91, 21-53.

Sabin, A.L., Pisias, N.G., 1996. Sea surface temperature changes in the northeastern Pacific Ocean during the past 20,000 years and their relationship to climate Change in northwestern North America. Quaternary Research 46, 48-61.

Sadek-Kooros, H., 1975. Intentional Fracturing of Bone: Description of Criteria. In: Clason, A.T. (Ed.), Archaeozoological Studies. North Holland Publishing Co., Amsterdam, pp. 139-150.

Saltonstall, P., Carver, G.A., 2002. 10 earthquakes, subsidence, prehistoric site attrition and the archaeological record: A view from the Settlement Point site, Kodiak Archipelago, Alaska. Natural Disasters, Catastrophism and Cultural Change 45, 172.

Sanger, D., 1981. Unscrambling messages in the midden. Archaeology of Eastern North America 9, 37-42.

Sauer, M., 1802. An Account of a Geographical and Astronomical Expedition to the Northern Parts of Russia: For Ascertaining the Degrees of Latitude and Longitude of the Mouth of the River Kovima, of the Whole Coast of the Tshutski, to East Cape, and of the Islands in the Eastern Ocean, Stretching to the American coast, Performed by Commodore Joseph Billings, in the Years 1785, &c to 1794 T. Cadell.

Saunders, J.J., 1977. Late Pleistocene Vertebrates of the Western Ozark Highland, Missouri. Illinois State Museum Reports of Investigations. Springfield, Missouri, 33.

Schaaf, J.M., 2009. Mink Island Site and the Amalik Bay Archaeological District, Katmai National Park and Preserve, Pacific coast of the Alaska: A High-Resolution, Long-Term Snapshot of Human Maritime Adaptations. In McManamon, F.P, Cordell, L.S., Lightfoot, K.G., and Milner, G.R. (Eds.), Archaeology in America: An Encyclopedia: West Coast and Arctic/Subarctic. Greenwood Press. Westport, pp.294-300.

Schalk, R.F., 1977. The Structure of an Anadromous Fish Resource. In: Binford, L.R. (Ed.), For Theory Building in Archaeology. Academic Press, New York, pp. 207-243.

Schnitzer, M., Khan, S.U., 1978. Soil Organic Matter. Elsevier, Amsterdam.

Schnute, J., Fournier, D., 1980. A new approach to length-frequency analysis: Growth Structure. Canadian Journal of Fisheries and Aquatic Sciences 37, 1337-1351.

Schoeninger, M.J , DeNiro, M.J.,1984. Nitrogen and carbon isotopic composition of bone collagen from marine and terrestrial animals. Geochimica et Cosmochimica Acta. 48, 625-639.

Schoeninger, M.J., Moore, K.M., Murray, M.L., Kingston, J.D., 1989. Detection of bone preservation in archaeological and fossil samples. Applied Geochemistry. 4, 281-292.

Sellars, R., McNay, M., 1984. Report to the Board of Game: Population Status and Management Considerations of the Brown Bear, Caribou, Moose and Wolves on the Alaska Peninsula. Report on file at Lake Clark-Katmai Studies Center, National Park Service, Anchorage, Alaska.

Shaw, R.D., Holmes, C.E., 1982. The Norton interaction sphere. Arctic Anthropology 19, 1-149.

Shipman, P., 1981. Life History of a Fossil: An Introduction to Taphonomy and Paleoecology. Harvard University Press, Cambridge, Massachusetts.

Shipman, P., Foster, G., Schoeninger, M., 1984. Burnt bones and teeth: An experimental study of color, morphology, crystal structure and shrinkage. Journal of Archaeological Science 11, 307-325.

Shipman, P., Rose, J., 1988. Bone Tools: An Experimental Approach. In: Olsen, S.L. (Ed.), Scanning Electron Microscopy in Archaeology. vol. British Archaeological Reports International Series, vol. 452, pp. 303-335.

Shotwell, J.A., 1955. An approach to the paleoecology of mammals. Ecology 36, 327-37.

Shotwell, J.A., 1958. Inter-community relationships in hemphillian (mid-Pliocene) mammals. Ecology 39, 271-282.

Sillen, A., 1989. Diagenesis of the Inorganic Phase of Cortical Bone. In: Price, T.D. (Ed.), The Chemistry of Prehistoric Human Bone. Cambridge University Press, Cambridge, pp. 211-229.

Skoog, R.O., 1968. Ecology of the Caribou (*Rangifer tarandus granti*) in Alaska. Ph.D. dissertation, University of California, Berkeley. University Microfilms, Ann Arbor.

Smith, E.A., 1991. Inujjamiut Foraging Strategies: Evolutionary Ecology of an Arctic Hunting Economy. Aldine, Chicago.

Smith, C. I., Neielsen-Marsh, C.M., Jans, M.M.E., Collins, M.J., 2007. Bone diagenesis in the European Holocene I: Patterns and mechanisms. Journal of Archaeological Science 34, 1485-1493.

Smith, H.A., 1983. Determination of seasonality in archaeological sites through examination of fish otoliths: A case study. Journal of Field Archaeology 10, 498-500.

Smith, E.A., Winterhalder, B., 1992. Natural Selection and Decision-Making. In: Smith, E.A., Winterhalder, B. (Eds.), Evolutionary Ecology and Human Behavior. Aldine, Chicago, pp. 25-60.

Smith, R.E., 2008. Structural Bone Density of Pacific cod (*Gadus macrocephalus*) and Halibut (*Hippoglossus stenolepis*): Taphonomic and Archaeological Implications, Master's Thesis, Portland State University.

Solomon, S.; Qin, D.; Manning, M.; Chen, Z.; Marquis, M.; Averyt, K.B.; Tignor, M.; and Miller, H.L., 2007. Climate Change 2007: The Physical Science Basis, Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press.

Solovjova, K.G., Vovnyanko, A.A., 2002. The Fur Rush. Phoenix Press, Anchorage.

Sowles, A.L., Hatch, S.A., Lensink, C.J., 1978. Catalog of Alaskan Seabird Colonies. Biological Services Program, U.S. Fish and Wildlife Service, Washington, D.C.

Spencer, P.J., 1979. Fish that men gnawed upon. Interim 6, 9-11.

Stafford, T.W., Jr.,Brendel, K., Duhamel, R., 1988. Radiocarbon, ^{13}C and ^{15}N analysis of fossil bone: Removal of humates with XAD-2 resin. Geochimica et Cosmochimica Acta 52, 2257-2267.

Stafford, T.W., Jr., Hare, L.P., Currie, E., Jull, A.J.T., Donahue, D.J., 1991. Accelerator radiocarbon dating at the molecular level. Journal of Archaeological Science 18, 35-72.

Steffian, A.F., 1992a. Archaeological coal in the Gulf of Alaska: A view from Kodiak Island. Arctic Anthropology 29, 111-129.

Steffian, A.F., 1992b. Fifty years after Hrdlicka: Further investigations at the Uyak site, Kodiak Island, Alaska. Anthropological Papers of the University of Alaska 24, 141-164.

Steffian, A.F., 2002. Cumilalhet- "Our Ancestors". In: Crowell, A.L., Steffian, A.F., Pullar, G.L. (Eds.) Looking Both Ways: Heritage and Identity of the Alutiiq People. University of Alaska Press, Fairbanks, pp. 99-136.

Steffian, A.F., Pontti Eufemio, E., Saltonstall, P., 2002. Early sites and microblade technology from the Kodiak Archipelago. Anthropological Papers of the University of Alaska, New Series 2, 1-38.

Stein, J.K., 1983. Earthworm activity: A source of potential disturbance of archaeological sediments. American Antiquity 48, 277-289.

Stein, J.K., 1984. Organic matter and carbonates in archaeological sites. Journal of Field Archaeology 11, 239-246.

Stein, J.K., 1992a. The Analysis of Sell Middens. In: Stein, J.K. (Ed.), Deciphering a Shell Midden. Academic Press, San Diego, pp. 1-24.

Stein, J.K., 1992b. Sediment Analysis of the British Camp Shell Midden. In: Stein, J.K. (Ed.), Deciphering a Shell Midden. Academic Press, San Diego, pp. 135-162.

Steiner, M.C., Kuhn, S.L., Weiner, S., Bar-Yosef, O., 1995. Differential burning, recrystallization, and fragmentation of archaeological bone. Journal of Archaeological Science 22, 223-237.

Stephens, D.W., Krebs, J.R., 1986. Foraging Theory. Princeton University Press, Princeton.

Stillwell, K.B., Kaufman, D.S., 1996. Late Wisconsin glacial history of the northern Alaska Peninsula, southwestern Alaska, USA. Arctic and Alpine Research 28, 475-487.

Strathe, C.J, 2009. Osteometric Analysis of Archaeologically Deposited Harbor Seal (*Phoca vitulina*) Remains as a Method for Inferring Prehistoric Seasonal Use at Mink Island, Alaska. Master's Thesis, University of Alaska Fairbanks.

Straty, R.R., 1981. Trans-shelf Movements of Pacific Salmon. In: Hood, D.W., Calder, J.A. (Eds.), The Eastern Bering Sea Shelf: Oceanography and Resources, Volume 1. United States Department of Commerce, U.S. Department of the Interior. United States Government Printing Office. Washington, D.C., pp. 575-595.

Stuvier, M., Polach, H.A., 1977. Discussion: Reporting of 14C data. Radiocarbon 19, 355-363.

Swift, M.J., Heal, O.W., Anderson, J.M., 1979. Decomposition in Terrestrial Ecosystems. Blackwell Scientific Publications, Oxford.

Szpak, P., 2011. Fish bone chemistry and ultrastructure: Implications for taphonomy and stable isotope analysis. Journal of Archaeological Science (2011), 1-15.

Tennessen, D.C., 2009. Stone Tools and Behavioral Ecology on Alaska's Katmai Coast. Ph.D. Dissertation, University of Minnesota, Minneapolis.

Testart, A., 1982. The significance of food storage among hunter-gatherers: Residence patterns population densities, and social inequalities. Current Anthropology 23, 523-537.

Teuscher, H., Adler, R., 1960. The Soil and its Fertility. Reinhold, New York.

The Climate Zone, n.d. www.theclimatezone.com, accessed, April 26tth, 2011.

Todd, L.C., 1983a. The Horner Site: Taphonomy of an Early Holocene Bison Bonebed, University of New Mexico, Albuquerque.

Todd, L.C., 1983b. Taphonomy: Fleshing out the dry bones of Plains prehistory. The Wyoming Archaeologist 26, 36-46.

Tont, S.A., Pearcy, W.G., Arnold, J.S., 1977. Bone structure of some marine vertebrates. Marine Biology 39, 191-196.

Townsend, J.B., 1974. Journals of the nineteenth century Russian priests to the Tanaina: Cook Inlet, Alaska. Arctic Anthropology 11, 1-30.

Triffitt, J.T., 1980. The Organic Matrix of Bone. In: Urist, M.R. (Ed.), Fundamental and Clinical Bone Physiology. Lippincott, Philadelphia/Toronto, pp. 45-82.

Tristram, G.R., Smith, R.H., 1963. The Amino Acid Composition of Some Purified Proteins. In: Anfinson, C.B., Anson, M.L., Esdale, J.T. (Eds.), Advances in Purified Proteins. Academic Press, New York, pp. 227-318.

Trump, B.F., Berezsky, I.K., Osornio-Vargas, A.R., 1981. Cell Death and the Disease Process: The Role of Calcium. In: Bowen, I.D., Lockshin, R.A. (Eds.), Cell Death in Biology and Pathology. Chapman Hall, London, pp.79-121.

Tucker, M.E., 1991. The Diagenesis of Fossils. In: Donovan, S.K. (Ed.), The Processes of Fossilization. Columbia University Press, New York, pp. 84-104.

Tuross, N., Behrensmeyer, A.K., Eanes, E.D., 1989. Strontium increases and crystallinity changes in taphonomic and archaeological bone. Journal of Archaeological Science 16, 661-672.

UniProt, n.d., www.UniProt.com, accessed Feburary 2nd, 2011.

United States Department of the Interior, Alaska Planning Group (APG), 1975. Final Environmental Statement. Proposed Katmai National Park, Alaska. Department of the interior, Washington, D.C.

United States Department of the Interior (USDOI), n.d., Brooks River Archaeological District. Electronic Document, http://tps.cr.nps/gov/detail.cfm?ResourceId=1740&ResourceType=District, accessed January 2nd, 2011.

United States Geological Survey (USGS), 1958. Kenai (topographic map) Topographic Bathymetric Series, 1:250,000.

United States National Park Service, 2006. Mammal Species Present in Katmai National Park and Preserve. Notes on File at Lake Clark-Katmai Studies Center, National Park Service, Anchorage, Alaska.

Vale, D., Gargett, R.H., 2002. Size Matters: 3-mm sieves do not increase richness in a fishbone assemblage from Arrawarra I, an aboriginal Australian shell midden of the mid-north coast of New South Wales, Australia. Journal of Archaeological Science 29, 57-63.

VanderHoek, R., 2009. Living Under the Shadow: Cultural Impacts of Volcanic Eruptions. Left Coast Press, Inc., Walnut Creek, CA.

VanderHoek, R., Myron, R., 2004. Cultural Remains from a Catastrophic Landscape: An Archaeological Overview and Assessment of Aniakchak National Monument and Preserve. United States Department of the Interior.

van Klinken, G.J., 1999. Bone collagen quality indicators for palaeodietary and radiocarbon measurements. Journal of Archaeological Science 26, 687-695.

van Klinken, G.J., Hedges, R.E.M., 1995. Experiments of collagen-humic interactions: Speed of humic uptake, and effects of diverse chemical treatments. Journal of Archaeological Science 22, 263-270.

van Klinken, G.L., Mook, W.G., 1990. Preparative high-performance liquid chromatographic separation of individual amino acids derived from fossil bone collagen. Radiocarbon 32, 155-164.

Veis, A., Sabsay, B., 1987. The Collagen of Mineralised Matrices. In: Genant, H.K. (Ed.), Bone and Mineral Research, vol. 5. Elsevier Science Publishers, Amsterdam, pp. 1-64.

Viereck, L.A., Little, E.L., 1991. Alaska Trees and Shrubs. Agricultural Handbook 410, USDA, Washington, D.C.

Von Endt, D.W., Ortner, D.J., 1984. Experimental effects of bone size and temperature on bone diagenesis. Journal of Archaeological Science 11, 247-253.

Wada, E., 1987. ^{15}N and ^{13}C abundances in marine environments with emphasis on biogeochemical structure of the food web. Isotopenpraxis 23, 320-322.

Wada, E.,Terazaki, M., Kabaya, Y., Nemoto, T., 1987. ^{15}N and ^{13}C abundances in the Antarctic Ocean with emphasis on the biogeochemical structure of the food web. Deep-Sea Research 34, 829-841

Waksman, S.A., Iyer, K.R.N., 1932. Contribution to our knowledge of the chemical nature and origin of humus: I, on the synthesis of the "humus nucleus". Soil Science 34, 43-69.

Wang, L.,An, X., Yang,F., Xin, Z, Zhao, L., Hu, Q., 2008. Isolation and characterisation of collagens from the skin, scale and bone of deep-sea redfish (*Sebases mentella*). Food Chemistry 108, 616-623.

Wahrhaftig, C., 1965. Physiographic Divisions of Alaska. U.S. Geological Survey Professional Paper No. 482.

Watson, J.P.N., 1979. The estimation of the relative frequencies of mammalian species: Khirokitia, 1972. Journal of Archaeological Science 6, 127-137.

Weingartner, T., 2005. Physical and Geological Oceanography: Coastal Boundaries and Coastal and Ocean Circulation. In: Mundy, P.R. (Ed.),The Gulf of Alaska Biology and Oceanography. Alaska Sea Grant College Program, Fairbanks, pp. 35-48.

Wepestad, V.G., Barton, L.H., 1981. Distribution, Migration and Status of Pacific Herring. In: Hood, D.W., Calder, J.A. (Eds.), The Eastern Bering Sea Shelf: Oceanography and Resources, Volume 1. United States Department of Commerce, U.S. Department of the Interior. United States Government Printing Office, Washington, pp. 509-525.

West, C.F., 2009. Human Dietary Response to Resource Abundance and Climate Change. Unpublished Ph.D. Dissertation, Department of Anthropology, University of Washington, Seattle.

Western Regional Climate Center, n.d. Alaska Climate Summaries. Electronic document, http://www.wrec.dri.edu/summary/climsmak.html, accessed November 30, 2005.

Wheeler, A., Jones, A.K.G., 1989. Fishes. Cambridge University Press, Cambridge.

White, D.C., Hannus, L.A., 1983. Chemical weathering of bone in archaeological sites. American Antiquity 48,316-322.

White, T.D., 1992. Prehistoric Cannibalism at Mancos 5MTUMR-2346. Princeton University Press, Princeton.

White, T.E., 1953. A method of calculating the dietary percentage of various food animals utilized by Aboriginal peoples. American Antiquity 18, 396-398.

Whitmer, A.M., Ramenofsky, A.F., Thomas, J., Thibodeaux, L., Field, S.D., Miller, B.J., 1989. Stability or instability the role of diffusion in trace element studies. Archaeological Method and Theory 1, 205-273.

Wiles, G.C., Calkin, P.E., 1994. Late Holocene, high-resolution glacial chronologies and climate, Kenai Mountains, Alaska. Geological Society of America Bulletin 106, 281-303.

Wiles, G.C., Calkin, P.E., Post, A., 1995. Glacier fluctuations in the Kenai Fjords, Alaska, U.S.A.: An evaluation of controls on iceberg-calving glaciers. Arctic and Alpine Research 27, 234-245.

Wiles, G.C., d'Arrigo, R.D., Jacoby, G.C., 1998. Gulf of Alaska atmosphere-ocean variability of recent centuries inferred from coastal tree-ring records. Climatic Change 38, 289-306.

Wilson, J.G., Overland, J.E., 1986. Meteorology. In: Hood, D.W., Zimmerman, S.T. (Eds.), The Gulf of Alaska: Physical Environment and Biological Resources. United States Department of Commerce, U.S. Department of the Interior. United States Government Printing Office, Washington, pp. 31-54.

Wilson, L., Pollard, M., 2002. Here today, gone tomorrow? Integrated experimentation and geochemical modeling in studies of archaeological diagenetic change. Accounts of Chemical Research 35, 644-651.

Winterhalder, B., 1981. Optimal Foraging Strategies and Hunter-Gatherer Research in Anthropology: Theories and Models. In: Winterhalder, B., Smith, E.A. (Eds.), Hunter Gatherer Foraging Strategies. University of Chicago Press, Chicago, pp. 13-35.

Winterhalder, B., Goland, C., 1997. An Evolutionary Ecology Perspective on Diet Choice and Plant Domestication. In: Gremillion, K.J. (Ed.), People, Plants, and Landscapes: Studies in Paleoethnobotany. University of Alabama Press, Tuscaloosa, pp. 123-160.

Witten, P.E., Huysseune, A., 2009. A comparative view on mechanisms and functions of skeletal remodeling in teleost fish, with special emphasis on osteoclasts and their function. Biological Review 84, 315-346.

Wood, W.R., Johnson, D.L., 1978. A Survey of Disturbance in Archaeological Site Formation. In: Schiffer, M.B. (Ed.), Advances in Archaeological Method and theory, Vol. 1. Academic Press, Orlando, pp. 315-381.

Workman, W.B., 1966. Archaeological reconnaissance on Chirikof Island, Kodiak Group: A preliminary report. Arctic Anthropology 3, 185-192.

Workman, W.B., 1969. Contributions to the Prehistory of Chirikof Island, Southwestern Alaska. Unpublished M.A. Thesis, Department of Anthropology, University of Wisconsin, Madison.

Workman, W.B., 1979. The Significance of Volcanism in the Prehistory of Subarctic Northwest North America. In: Sheets, P.D., Grayson, D.K. (Ed.), Volcanic Activity and Human Ecology. Academic Press, New York, pp. 339-371.

Workman, W.B., 1980. Continuity and change in the prehistoric record from southern Alaska. Senri Ethnological Studies 4, 49-101.

Workman, W.B., 1982. Beyond the southern frontier: The Norton culture and the western Kenai Peninsula. Arctic Anthropology 19, 101-121.

Workman, W.B., 1998a. Archaeology of the southern Kenai Peninsula. Arctic Anthropology 35, 146-159.

Workman, W.B., 1998b. Northern Archaic Tradition. In: Gibbon, G. (Ed.), Archaeology of Prehistoric Native America: An Encyclopedia. Garland Publishing, Inc., New York, pp. 567-569.

Wyckoff, R.W.G., 1972. The Biochemistry of Animal Fossils. The Williams and Wilkins Company, Baltimore.

Yarborough, M.R., Yarborough, L.F., 1998. Prehistoric maritime adaptations of Prince William Sound and the Pacific coast of the Kenai Peninsula. Arctic Anthropology 35, 32-145.

Yellen, J.E., 1991. Small mammals: Post-discard patterning of !Kung San faunal remains. Journal of Anthropological Archaeology 10, 152-192.

Yesner, D.R., 1989. Osteological remains from Larsen Bay, Kodiak Island, Alaska. Arctic Anthropology 26, 96-106.

Yesner, D.R., 1992. Evolution of subsistence in the Kachemak Tradition: Evaluating the north pacific maritime stability model. Arctic Anthropology 29, 167-181.

Yesner, D.R., 1998. Origins and development of maritime adaptations in the northwest pacific region of North America: A zooarchaeological perspective. Arctic Anthropology 35, 204-222.

Yoshino, M., Kinijima, T., Miyasaka, S, Sato, H., Seta, S., 1991. Microscopic study on estimation of time since death in skeletal remains. Forensic Science International 49, 143-158.

Appendix A: Modified Bell *et al.* (2001) Pretreatment Method

a. Clean fish bones-dental pick, sonicate.

b. Powder fish bones-freeze dry bones, grind into a fine powder (<63μm) using a bone mill.

c. Weigh-approximately 0.10g of fish bone powder.

d. Remove lipids-add 1.5ml of 3:2 hexane: isopropanol extraction solvent- 5 minutes total.

e. Evaporate 3:2 hexane: isopropanol- under fume hood, sample air-dries overnight.

f. Demineralize- add 1.5ml of 0.5 M HCL for 60 minutes total.

g. Rinse #1- rinse sample with ultrapure water three times.

h. Alkali treatment- add 1.5 ml of 0.1M NaOH to the sample for 10 minutes total.

i. Rinse #2- rinse sample with ultrapure water three times.

j. Freeze- place tubes in a freezer overnight.

k. Freeze Dry- place tubes in a vacuum flask and freeze dry overnight.

l. Weigh samples- weigh freeze-dried samples (0.1 to 0.4mg).

m. Submit samples to the Alaska Stable Isotope Facility for $\delta^{13}C$ and $\delta^{15}N$ analysis- samples are run using an EA IRMS continuous flow system using international standards. $\delta^{13}C$ (relative to VPDB), $\delta^{15}N$ (relative to AIR).

n. Assess quality of $\delta^{13}C$ and $\delta^{15}N$ values using multiple indicators-

i. Compare ancient to modern $\delta^{13}C$ and $\delta^{15}N$ values.

ii. Examine percent collagen yield.

iii. Percent carbon and nitrogen by weight.

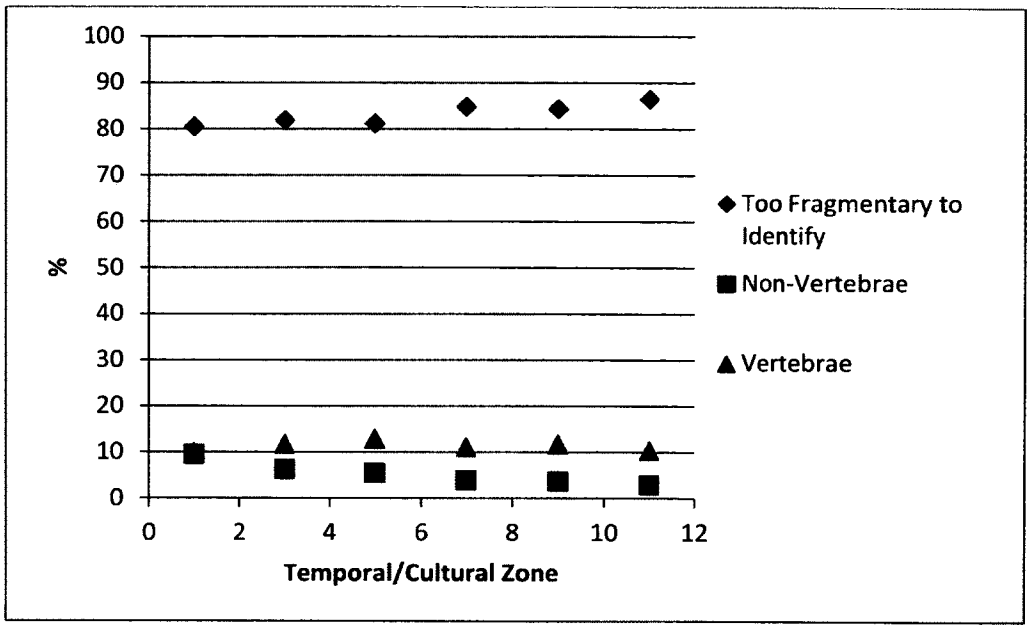
iv. Atomic C: N.

Appendix B: Fish species present in the waters surrounding the Kodiak Archipelago and the Alaska Peninsula. List from Rogers *et al.*, 1986 and Kopperl, 2003).

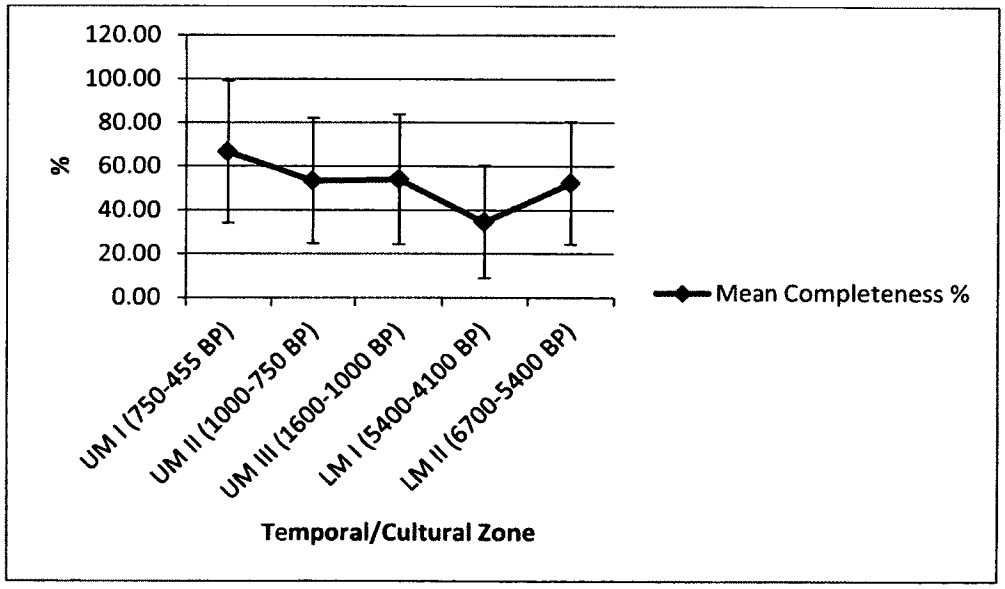
Taxon-Family	Common Name	Genus and Species	Common Name	Habitat
Agonidae	poachers	*Agonus acipenserinus*	sturgeon poacher	near-shore pelagic
Agonidae	poachers	*Anoplagonus inermis*	smooth allogatorfish	near-shore pelagic
Agonidae	poachers	*Ocella dodecadron*	Bering poacher	near-shore pelagic
Agonidae	poachers	*Pallasina barbata*	Tubenose poacher	near-shore pelagic
Ammodytidae	sand lances	*Ammodytes hexapterus*	Pacific sand lance	wide-spread near-shore
Anarhichadidae	wolf-fishes	*Anarichas orientalis*	Bering woffish	near-shore pelagic
Anarhichadidae	wolf-fishes	*Anarrhichthys ocellatus*	wolf-eel	near-shore rocky reefs
Anoplopomatidae	sablefishes	*Anoplopoma fimbria*	sablefish (black cod)	off-shore
Aulorhynchidae	tubesnouts	*Aulorhynchusflavidus*	tubesnout	kelp-beds
Bathymasteridae	ronquils	*Bathymaster caeruleofasciatus*	Alaskan ronquil	near-shore pelagic
Bathymasteridae	ronquils	*Bathymaster signatus*	searcher	near-shore pelagic
Bathymasteridae	ronquils	*Ronquilus jordani*	northern ronquil	near-shore pelagic
Chondrychthes	cartilaginous fish	*Raja binoculata*	big skate	near-shore pelagic
Chondrychthes	cartilaginous fish	*Raja rhina*	longnose skate	near-shore pelagic
Chondrychthes	cartilaginous fish	*Squalus acanthias*	spiny dogfish	near-shore pelagic
Clupeidae	herring	*Clupea harengus pallasii*	Pacific herring	shallows and bays in spring
Cottidae	sculpins	*Artedius fenestralis*	padded sculpin	near-shore rocky reefs
Cottidae	sculpins	*Blepsias bilobus*	crested sculpin	near-shore rocky reefs
Cottidae	sculpins	*Blepsias cirrhosus*	silverspotted sculpin	shallow bays
Cottidae	sculpins	*Clinocottus acuticeps*	sharpnose sculpin	shallow bays
Cottidae	sculpins	*Dasycottus setiger*	spinyhead sculpin	near-shore pelagic
Cottidae	sculpins	*Enophrys bison*	buffalo sculpin	near-shore rocky reefs
Cottidae	sculpins	*Gilbertidia sigalutes*	soft sculpin	near-shore pelagic
Cottidae	sculpins	*Gymnocanthus galeatus*	armorhead sculpin	near-shore pelagic
Cottidae	sculpins	*Gymnocanthus pistilliger*	threaded sculpin	near-shore pelagic
Cottidae	sculpins	*Hemilepidotus hemilepidotus*	red irish lord	wide-spread near-shore
Cottidae	sculpins	*Hemilepidotus jordani*	yellow irish lord	near-shore pelagic
Cottidae	sculpins	*Hemitripterus bolini*	bigmouth sculpin	near-shore pelagic
Cottidae	sculpins	*Icelinus borealis*	northern sculpin	near-shore pelagic
Cottidae	sculpins	*Icelus spiniger*	thorny sculpin	off-shore
Cottidae	sculpins	*Leptocottus armatus*	Pacific staghorn sculpin	wide-spread near-shore
Cottidae	sculpins	*Myoxocephalus jaok*	plain sculpin	wide-spread near-shore
Cottidae	sculpins	*Myoxocephalus polycantocephalus*	great sculpin	wide-spread near-shore
Cottidae	sculpins	*Myoxocephalus scorpius*	shorthorn sculpin	wide-spread near-shore
Cottidae	sculpins	*Nautichthys oculofaciatus*	sailfin sculpin	wide-spread near-shore
Cottidae	sculpins	*Nautichthys pribilovius*	eyeshade sculpin	wide-spread near-shore
Cottidae	sculpins	*Oligottus maculosus*	tidepool sculpin	near-shore rocky reefs
Cottidae	sculpins	*Psychrolutes paradoxus*	tadpole sculpin	near-shore pelagic
Cottidae	sculpins	*Radulinus asperellus*	slim sculpin	near-shore pelagic
Cottidae	sculpins	*Synchirus gilli*	manacled sculpin	wide-spread near-shore
Cottidae	sculpins	*Triglops forficate*	scissortail sculpin	near-shore pelagic
Cottidae	sculpins	*Triglops macellus*	roughspine sculpin	near-shore pelagic
Cottidae	sculpins	*Triglops pingelii*	ribbed sculpin	near-shore pelagic
Cyclopteridae	snailfish	*Aptocyclus ventricosus*	smooth lumpsucker	near-shore pelagic
Cyclopteridae	snailfish	*Liparis callyodon*	spotted snailfish	wide-spread near-shore, intertidal
Cyclopteridae	snailfish	*Liparis cycloptus*	ribbon snailfish	wide-spread near-shore, intertidal
Cyclopteridae	snailfish	*Liparis dennyi*	marbled snailfish	wide-spread near-shore
Cyclopteridae	snailfish	*Liparis fucensis*	slipskin snailfish	near-shore pelagic
Cyclopteridae	snailfish	*Liparis mucosus*	slimy snailfish	wide-spread near-shore, intertidal

Taxon-Family	Common Name	Genus and Species	Common Name	Habitat
Gadidae	cods and haddocks	*Eleginus gracilis*	saffron cod	near-shore in winter
Gadidae	cods and haddocks	*Gadus macrocephalus*	Pacific cod	near-shore in spring/summer
Gadidae	cods and haddocks	*Microgadus proximus*	Pacific tomcod	near-shore pelagic
Gadidae	cods and haddocks	*Theragra chalcogramma*	walleye pollock	near-shore pelagic
Gasterosteidae	stickelbacks	*Gasterosteus aculeatus*	threespine stickleback	wide-ranging, salt/brackish
Hexagrammidae	greenlings and lingcod	*Hexagrammos decagrammus*	kelp greenling	kelp-beds and reefs
Hexagrammidae	greenlings and lingcod	*Hexagrammos lagocephalus*	rock greenling	kelp-beds and reefs
Hexagrammidae	greenlings and lingcod	*Hexagrammos octogrammus*	masked greenling	near-shore rocky reefs
Hexagrammidae	greenlings and lingcod	*Hexagrammous stelleri*	whitespotted greenling	near-shore rocky reefs
Hexagrammidae	greenlings and lingcod	*Ophiodon elongatus*	lingcod	near-shore pelagic
Hexagrammidae	greenlings and lingcod	*Pleurogrammus monopterygius*	atka mackerel	near-shore pelagic
Osmeridae	smelts	*Hypomesius pretiosus*	surf smelt	beaches, seasonal
Osmeridae	smelts	*Mallotus vilosus*	capelin	beaches, seasonal
Osmeridae	smelts	*Thaleichthys pacificus*	eulachon	large rivers, summer
Pholididae	gunnels	*Apodichthys flavidus*	penpoint gunnel	wide-spread near-shore
Pholididae	gunnels	*Pholis clemensi*	longfin gunnel	near-shore pelagic
Pholididae	gunnels	*Pholis laeta*	crescent gunnel	wide-spread near-shore
Pleuronectidae	flatfishes	*Atheresthes stomias*	arrowtooth flounder	near-shore, sandy bottom
Pleuronectidae	flatfishes	*Glyptocephalus zacharius*	rex sole	off-shore, sand and mud bottom
Pleuronectidae	flatfishes	*Hippoglossoides elassodon*	flathead sole	wide-spread near-shore, silt/mud
Pleuronectidae	flatfishes	*Hippoglossus stenolepis*	Pacific halibut	wide-spread near-shore summer
Pleuronectidae	flatfishes	*Isopsetta isolepis*	butter sole	near-shore, mud or silt bottom
Pleuronectidae	flatfishes	*Lepidopsetta bilineata*	northern rock sole	near-shore, rocky/sandy bottom
Pleuronectidae	flatfishes	*Limanda aspera*	yellowfin sole	near-shore, sandy bottom
Pleuronectidae	flatfishes	*Microstomus pacificus*	dover sole	off-shore, sand and mud bottom
Pleuronectidae	flatfishes	*Parophrys vetulus*	English sole	near-shore, sandy bottom
Pleuronectidae	flatfishes	*Platichthys stellatus*	starry flounder	wide-spread, near-shore brackish
Pleuronectidae	flatfishes	*Pleuronectes quadrituberculatus*	Alaska plaice	off-shore
Pleuronectidae	flatfishes	*Psettichthys melanostictus*	sand sole	near-shore, sandy bottom
Salmonidae	salmon, trout, and char	*Oncorhynchus gorbuscha*	pink salmon	most rivers, spring-summer
Salmonidae	salmon, trout, and char	*Oncorhynchus keta*	chum salmon	most rivers, summer
Salmonidae	salmon, trout, and char	*Oncorhynchus kisutch*	coho salmon	larger rivers, late summer-fall
Salmonidae	salmon, trout, and char	*Oncorhynchus mykiss*	rainbow trout	larger rivers, summer
Salmonidae	salmon, trout, and char	*Oncorhynchus nerka*	sockeye salmon	rivers with lakes, early summer
Salmonidae	salmon, trout, and char	*Oncorhynchus tshawytscha*	chinook salmon	large rivers, summer
Salmonidae	salmon, trout, and char	*Salvelinus malma*	dolly varden	most rivers, spring-fall
Scorpaenidae	rockfishes	*Sebastes alutus*	Pacific ocean perch	mainly off-shore
Scorpaenidae	rockfishes	*Sebastes ciliatus*	dusky rockfish	near-shore rocky reefs
Scorpaenidae	rockfishes	*Sebastes crameri*	darkblotched rockfish	mainly off-shore
Scorpaenidae	rockfishes	*Sebastes melanops*	black rockfish	near-shore rocky reefs
Scorpaenidae	rockfishes	*Sebastes nigrocintus*	tiger rockfish	near-shore rocky reefs
Stichaeidae	warbonnets and pricklebacks	*Anoplarchus purpurescens*	high cockscomb	wide-spread near-shore
Stichaeidae	warbonnets and pricklebacks	*Lumpenella longirostris*	longnose prickleback	near-shore pelagic
Stichaeidae	warbonnets and pricklebacks	*Lumpenus maculates*	daubed shanny	near-shore pelagic
Stichaeidae	warbonnets and pricklebacks	*Lumpenus medius*	stout eelblenny	near-shore pelagic
Stichaeidae	warbonnets and pricklebacks	*Lumpenus sagitta*	snake prickleback	near-shore pelagic
Stichaeidae	warbonnets and pricklebacks	*Poroclinus rothrocki*	white daubed prickleback	near-shore pelagic
Stichaeidae	warbonnets and pricklebacks	*Stichaeus punctatus*	Arctic shanny	near-shore pelagic
Trichodontidae	sandfishes	*Trichodon trichodon*	Pacific sandifish	shallows near-shore
Zaproridae	prowfishes	*Zaprora sileneus*	prowfish	near-shore pelagic
Zoarcidae	eelpouts	*Lycodes brevipes*	shortfin eelpout	near-shore pelagic
Zoarcidae	eelpouts	*Lycodes palearis*	wattled eelpout	near-shore pelagic

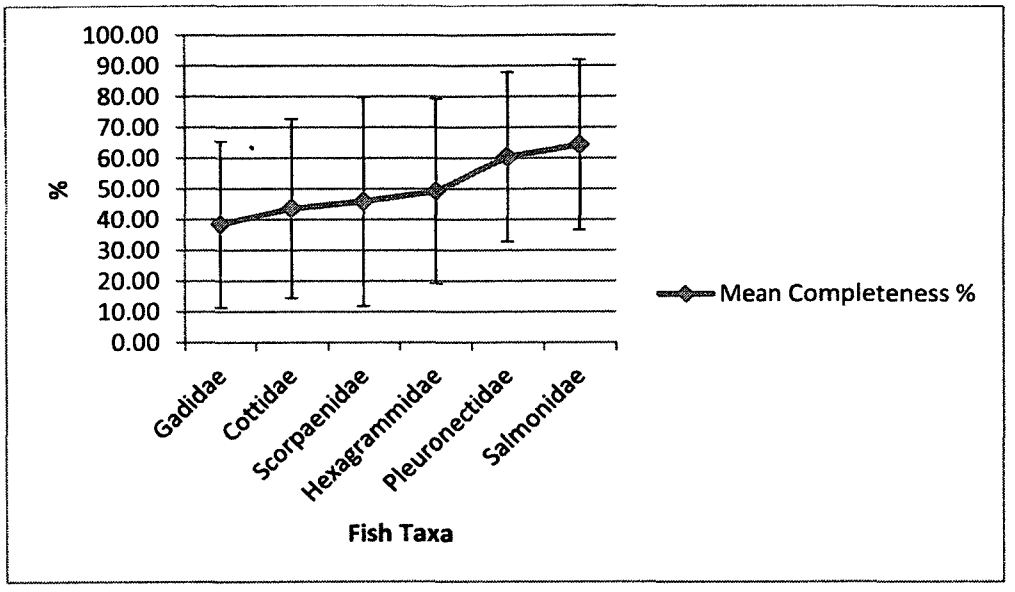
Appendix C: Skeletal element fragmentation by temporal/cultural zone, fish taxa, anatomical region, robusticity groupings, and shape categories



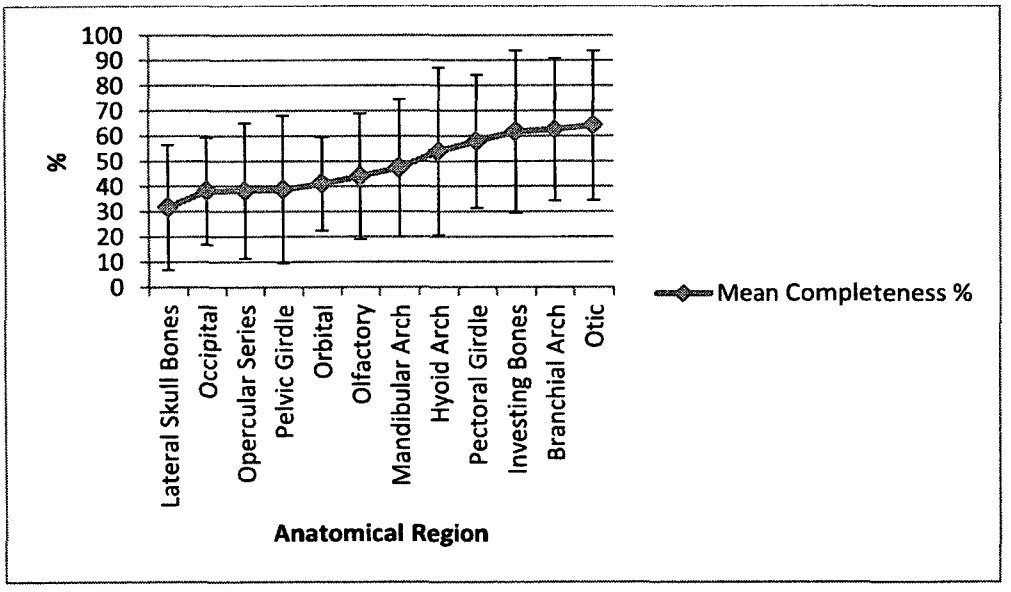
Appendix C.1 Percent of fish skeletal elements that are too fragmentary to identify beyond class, non-vertebrae, and vertebrae. Radiocarbon age ranges are calibrated (2-sigma).



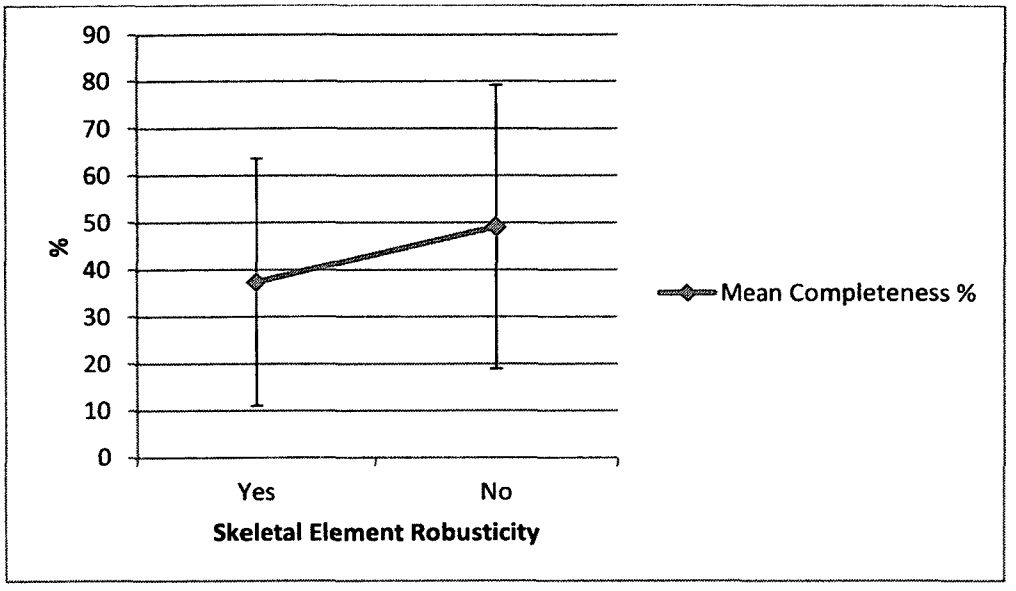
Appendix C.2. Mean completeness % and SD values of Mink Island fish bones aggregated by temporal/cultural zones. Radiocarbon age ranges are calibrated (2-sigma).



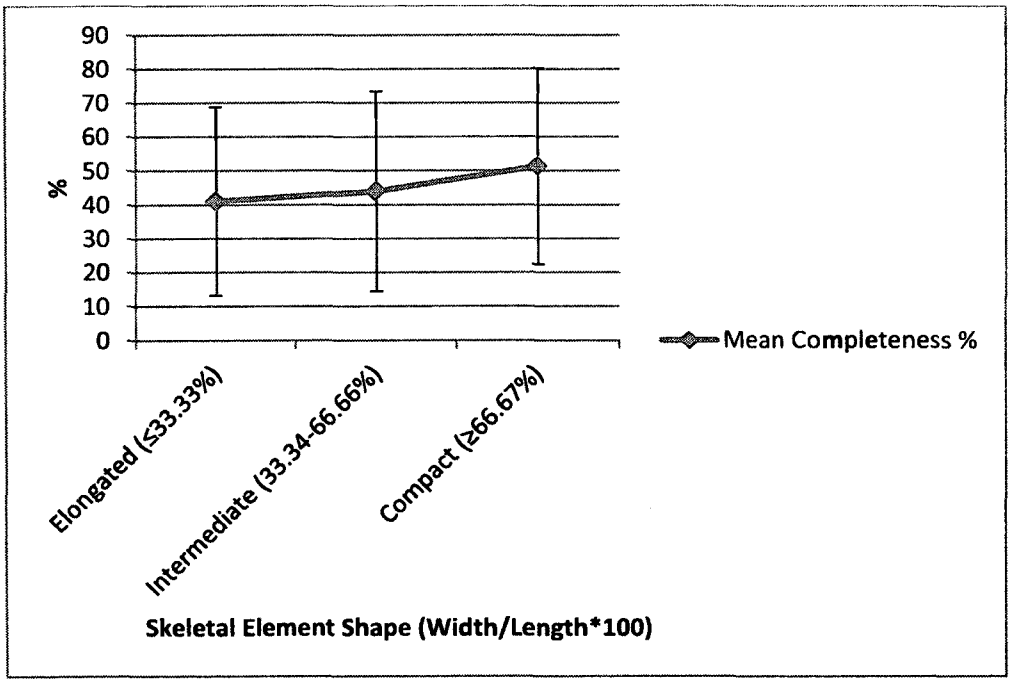
Appendix C.3. Mean completeness % values of family-level taxa recovered from the Mink Island site.



Appendix C.4. Mean completeness % and SD values of Mink Island fish bones aggregated by anatomical region.



Appendix C.5. Mean completeness % and SD values of robust and non-robust skeletal elements recovered from the Mink Island site.



Appendix C.6. Mean completeness % and SD values of Mink Island 2-D shape categories.

Appendix D: Mink Island and Modern Pacific cod Samples for Stable Isotope Analysis

Sample Number	level	Radiocarbon Years BP (2 Sigma)	Skeletal Element	physical appearance class	% Collagen Yield	Bulk Bone % Nitrogen	Buik Bone % Carbon	Expected %C from %N	Carbon Contamination	%N by Weight	%C by Weight	δ15N	δ13C	Atomic C: N
BB-07	1	<535	Dentary	2	16	2.85	12.29	8.68	3.61	19.36	53.62	17.81	-12.84	3.23
BB-08	3a	535	Dentary	2	20	2.53	11.24	7.87	3.37	17.11	47.94	16.47	-13.52	3.27
BB-09	4d	735	Dentary	2	8.1	2.79	11.30	8.53	2.77	17.62	48.08	16.36	-13.49	3.18
BB-10	5a	910	Dentary	2	22	2.85	11.66	8.68	2.98	8.97	25.98	17.43	-12.24	3.38
BB-11	6	915	Dentary	2	16	2.55	11.24	7.92	3.32	19.77	54.84	17.65	-11.9	3.24
BB-12	1	5050	Dentary	2	6.5	1.55	9.32	5.40	3.92	13.32	39.01	17.13	-12.92	3.42
BB-13	2	5050	Dentary	2	6.6	1.97	10.14	6.46	3.68	15.19	41.82	16.01	-12.85	3.21
BB-14	3	5050	Dentary	2	7	2.12	9.32	6.84	2.48	17.7	48.71	17.54	-11.55	3.21
BB-15	4	5050	Dentary	3	6.4	1.36	8.70	4.92	3.78	14.35	42.53	17.8	-12.78	3.46
BB-16	5	5050	Dentary	2	6.7	2.12	10.18	6.84	3.34	17.41	49.19	16.08	-13.36	3.3
BB-17	8	5352	Dentary	2	6.7	1.87	10.01	6.21	3.80	16.99	47.38	16.33	-13.01	3.25
BB-18	9	5352	Dentary	3	3.7	1.33	8.60	4.84	3.76	15.26	43.97	17.2	-12.45	3.36
BB-19	10	5352	Dentary	4	6.4	1.17	12.63	4.44	8.19	9.77	31.23	16.42	-14.3	3.73
BB-20	1	<535	Quadrate	2	30.4	3.17	12.18	9.49	2.69	9.59	30.17	15.97	-14.62	3.67
BB-21	3a	535	Quadrate	3	9	2.45	10.48	7.67	2.81	16.24	47.7	18.94	-13.5	3.43
BB-22	4a	745	Quadrate	3	9.2	2.85	10.33	8.68	1.65	17.11	48.18	16.32	-12.21	3.29
BB-23	5a	910	Quadrate	2	12	3.61	12.57	10.60	1.97	20.17	56.72	16.18	-12.87	3.28
BB-24	6	915	Quadrate	2	14.4	2.97	11.20	8.99	2.21	17.15	48.59	16.84	-12.27	3.31
BB-25	7	1510	Quadrate	3	18.7	2.20	9.63	7.04	2.59	12.89	36.92	18.33	-11.7	3.34
BB-26	1	5050	Quadrate	3	6.1	2.27	9.97	7.22	2.75	17.54	49.27	17.39	-12.02	3.28
BB-27	2	5050	Quadrate	4	6.1	2.25	9.57	7.17	2.40	16.6	47.01	17.91	-12.77	3.3
BB-28	3	5050	Quadrate	2	9.1	2.17	9.67	6.96	2.71	16.58	46.63	16.76	-12.7	3.28
BB-29	4	5050	Quadrate	3	6.5	1.35	8.28	4.89	3.39	15.76	48.34	17.55	-12.56	3.58
BB-30	5	5050	Quadrate	2	N/A	2.33	10.75	7.37	3.38	N/A	N/A	N/A	N/A	N/A

BB-31	7	5352	Quadrate	2	7.3	1.91	9.55	6.31	3.24	15.9	45.75	16.19	-12.94	3.38
BB-32	9	5352	Quadrate	3	5.7	1.96	9.86	6.43	3.43	15.96	46.17	17.57	-12.68	3.38
BB-33	10	5352	Quadrate	2	5.9	1.58	8.70	5.47	3.23	15.82	45.19	17.22	-11.54	3.33
BB-34	1	<535	Vomer	3	13	2.99	11.84	9.04	2.80	15.02	44.26	16.31	-12.68	3.44
BB-35	3a	535	Vomer	2	11.3	3.14	11.37	9.42	1.95	15.97	46.7	14.34	-12.52	3.41
BB-36	4d	735	Vomer	2	10.4	2.43	10.01	7.62	2.39	15.59	45.14	16.86	-12.22	3.38
BB-37	5a	910	Vomer	2	10.3	3.23	11.69	9.64	2.05	16.8	47.4	18.75	-11.74	3.29
BB-38	6	915	Vomer	2	9	2.59	11.27	8.03	3.24	21.37	61.18	18.01	-11.78	3.34
BB-39	7	1510	Vomer	2	7.6	2.74	10.63	8.40	2.23	15.31	43.88	15.48	-12.7	3.34
BB-40	1	5050	Vomer	3	5.2	1.40	8.03	5.02	3.01	13.2	39.65	17.45	-12.99	3.51
BB-41	2	5050	Vomer	2	5.6	1.87	9.52	6.21	3.31	13.55	42.16	15.51	-13.14	3.63
BB-42	3	5050	Vomer	3	4.9	1.53	8.42	5.35	3.07	15.56	44.7	15.97	-12.51	3.35
BB-43	4	5050	Vomer	2	7	2.15	9.44	6.91	2.53	15.63	45.07	16.42	-12.15	3.37
BB-44	5	5050	Vomer	2	5.5	1.47	8.84	5.19	3.65	15.22	46.24	14.88	-14.09	3.55
BB-45	7	5352	Vomer	3	3	0.96	7.07	3.90	3.17	12.42	37.9	14.7	-14.47	3.56
BB-46	8	5352	Vomer	2	2.2	0.78	6.97	3.45	3.52	11.87	37.06	18.37	-13.13	3.64
BB-47	10	5352	Vomer	3	2.9	0.52	6.89	2.79	4.10	7.86	31.56	15.77	-16.22	4.69
BB-48	1	<535	Hyomandibular	2	13	3.22	11.61	9.62	1.99	13.86	40.01	15.4	-12.74	3.37
BB-49	3a	535	Hyomandibular	2	12	3.21	11.60	9.59	2.01	17.88	49.92	16.67	-12.84	3.26
BB-50	4a	745	Hyomandibular	2	24.9	3.12	11.02	9.37	1.65	15.49	45.05	15.98	-12.72	3.39
BB-51	5a	910	Hyomandibular	2	22.6	2.60	10.44	8.05	2.39	16.37	46.29	17.69	-11.1	3.3
BB-52	6	915	Hyomandibular	2	10.9	3.14	11.38	9.42	1.96	16.92	47.12	15.3	-13.32	3.25
BB-53	7	1510	Hyomandibular	3	9.6	2.97	10.11	8.99	1.12	16.66	46.04	15.49	-12	3.23
BB-54	1	<535	Atlas Vertebra	2	11.2	2.83	11.69	8.63	3.06	15.52	46.76	17.09	-13.54	3.52
BB-55	3a	535	Atlas Vertebra	2	20	2.99	10.80	9.04	1.76	15.01	44.66	16.59	-12.8	3.47
BB-56	4a	745	Atlas Vertebra	2	10	2.89	10.60	8.78	1.82	17.75	49.18	16.97	-11.31	3.23
BB-57	5a	910	Atlas Vertebra	3	20.3	2.67	10.44	8.23	2.21	17.08	50.86	18.63	-13	3.48
BB-58	6	915	Atlas Vertebra	2	26.6	2.82	10.53	8.61	1.92	14.98	41.76	15.42	-12.57	3.25

BB-59	1	5050	Atlas Vertebra	3	10.5	1.73	9.22	5.85	3.37	14.17	41.22	17.4	-12.14	3.39
BB-60	2	5050	Atlas Vertebra	2	11.5	1.55	8.12	5.40	2.72	15.18	42.88	16.67	-11.97	3.3
BB-61	3	5050	Atlas Vertebra	3	11.4	1.86	8.37	6.18	2.19	15.19	42.13	18	-11.01	3.24
BB-62	4	5050	Atlas Vertebra	3	4.8	1.14	7.90	4.36	3.54	14.26	40.86	16.48	-12.49	3.34
BB-63	5	5050	Atlas Vertebra	3	7.5	1.81	9.37	6.05	3.32	14.04	40.2	16.03	-13.19	3.34
BB-64	6	5050	Atlas Vertebra	2	7.7	1.69	8.28	5.75	2.53	15.7	44.28	18.13	-10.99	3.29
BB-65	8	5352	Atlas Vertebra	3	6.3	1.83	8.25	6.10	2.15	14.76	42.45	16.75	-12.09	3.36
BB-66	10	5352	Atlas Vertebra	2	11	1.74	9.30	5.88	3.42	14.65	41.41	18.27	-11.33	3.3
BB-67	1	<535	Maxilla	2	12	3.05	11.49	9.19	2.30	17.16	48.32	17.28	-12.09	3.29
BB-68	3a	535	Maxilla	3	11	2.30	10.09	7.29	2.80	17.07	48.8	16.45	-11.93	3.34
BB-69	4d	735	Maxilla	3	9.3	3.29	11.39	9.80	1.59	16.54	46.2	15.46	-12.26	3.26
BB-70	5a	910	Maxilla	3	10.4	3.06	11.29	9.21	2.08	15.85	45.56	15.72	-12.28	3.35
BB-71	6	915	Maxilla	3	8.3	2.29	9.34	7.27	2.07	16.52	46.29	17.59	-11.67	3.27
BB-72	1	5050	Maxilla	3	6.6	1.95	9.77	6.41	3.36	15.95	46.05	17.09	-12.03	3.37
BB-73	2	5050	Maxilla	2	4.1	1.61	8.89	5.55	3.34	15.53	44.76	17.16	-11.68	3.36
BB-74	3	5050	Maxilla	2	5.9	2.02	9.39	6.58	2.81	14.84	41.77	16.52	-12.49	3.28
BB-75	4	5050	Maxilla	3	6.9	1.97	8.96	6.46	2.50	15.48	43.59	17.69	-11.62	3.29
BB-76	5	5050	Maxilla	3	5.9	2.22	10.15	7.09	3.06	15.84	44.29	16.86	-12.11	3.26
BB-77	7	5352	Maxilla	4	4	1.39	9.26	4.99	4.27	14.85	45.28	17.65	-13.65	3.59
BB-78	9	5352	Maxilla	4	3.8	1.09	7.57	4.23	3.34	9.59	29.39	17.01	-13.47	3.58
PC-01	n/a	0	Dentary	1	21	5.14	14.2	14.47	-0.27	18.11	49.42	15.7	-12.54	3.18
PC-02	n/a	0	Dentary	1	22	5.09	14.29	14.35	-0.06	18.27	49.93	14.73	-13.7	3.19
PC-03	n/a	0	Dentary	1	23	5.26	14.61	14.78	-0.17	17.54	48.14	15.72	-12.08	3.2
PC-04	n/a	0	Dentary	1	22	5.29	14.4	14.85	-0.45	18.27	49.87	15.79	-13.32	3.19
PC-05	n/a	0	Dentary	1	22	5.31	14.8	14.9	-0.1	17.33	47.14	14.63	-13.09	3.17
PC-06	n/a	0	Dentary	1	22	4.8	13.59	13.61	-0.02	18.46	50.07	16.13	-12.47	3.16
PC-07	n/a	0	Dentary	1	28	4.94	13.8	13.97	-0.17	18.22	49.9	16.82	-12.23	3.2
PC-08	n/a	0	Dentary	1	23	5.07	14.32	14.29	0.03	18.12	49.41	15.78	-13.49	3.18

PC-09	n/a	0	Dentary	1	24	5.23	14.88	14.7	0.18	17.75	48.89	15.15	-13.82	3.21
PC-10	n/a	0	Dentary	1	24	5.28	14.88	14.83	0.05	17.23	47.02	14.96	-13.43	3.18
PC-11	n/a	0	Dentary	1	22	4.99	14.44	14.09	0.35	17.97	48.96	14.89	-13.95	3.18
PC-12	n/a	0	Dentary	1	18	4.88	13.91	13.81	0.1	18.35	50.12	15.58	-13.63	3.19
PC-13	n/a	0	Dentary	1	22	5.25	14.55	14.75	-0.02	17.1	46.78	15.06	-14.18	3.19
PC-14	n/a	0	Dentary	1	23	5.17	14.54	14.55	-0.01	18	49.4	14.79	-13.77	3.2
PC-15	n/a	0	Dentary	1	22	5.18	14.72	14.57	0.15	18.07	49.69	15	-13.06	3.21
PC-16	n/a	0	Dentary	1	22	1.58	4.76	5.47	-0.87	18.05	49.53	15.09	-14.28	3.2
PC-17	n/a	0	Dentary	1	26	5.06	14.48	14.27	0.21	17.94	49.49	15.02	-13.93	3.22
PC-18	n/a	0	Dentary	1	27	5.12	14.52	14.42	0.1	16.64	46.12	15.05	-14.11	3.23
PC-19	n/a	0	Dentary	1	19	5.09	14.4	14.35	0.05	18.11	49.37	14.36	-14.38	3.18
PC-20	n/a	0	Dentary	1	23	5.17	14.63	14.55	0.08	18.45	50.77	15.27	-13.98	3.21
PC-21	n/a	0	Dentary	1	24	5.14	14.43	14.47	-0.04	22.4	61.93	16.29	-13.86	3.23
PC-22	n/a	0	Dentary	1	22	5.27	14.61	14.8	-0.19	18.27	50.07	14.93	-14.27	3.2
PC-23	n/a	0	Dentary	1	25	5.11	14.39	14.4	-0.01	18.22	50.21	16.02	-12.72	3.22
PC-24	n/a	0	Dentary	1	22	5.03	14.3	14.19	0.11	18.02	49.32	14.75	-14.09	3.19
PC-25	n/a	0	Dentary	1	24	4.51	12.69	12.88	-0.19	18	49.25	15.05	-13.2	3.19
PC-26	n/a	0	Dentary	1	24	5.59	15.75	15.61	0.14	17.91	48.98	14.85	-13.94	3.19
PC-27	n/a	0	Dentary	1	23	5.07	14.26	14.29	-0.03	17.76	48.62	15.83	-13.84	3.19
PC-28	n/a	0	Dentary	1	23	5.14	14.65	14.47	0.18	17.96	49.41	14.71	-13.47	3.21
PC-29	n/a	0	Dentary	1	25	5.06	14.21	14.27	-0.06	18.3	50.07	14.93	-14.07	3.19
PC-30	n/a	0	Dentary	1	25	5.15	14.7	14.5	0.2	18.03	49.58	15.33	-13.59	3.21
PC-31	n/a	0	Dentary	1	25	5.03	14.23	14.19	0.04	18.11	49.32	14.78	-13.67	3.18

Appendix E: Color assessment of Mink Island Pacific cod samples

Sample Number	Calibrated Radiocarbon Intercept (Years BP)	Skeletal Element	Munsell color #1 (on untreated powdered bone)	Munsell color #2 (on NaOH treated powdered bone)	Munsell color #3 (on Hexane: Isopropanol, NaOH, and HCl treated powdered bone)
HJM-BB-07	450	Dentary	10YR 5/4 (yellowish brown)	10 YR 5/6 (yellowish brown)	10 YR 5/6 (yellowish brown)
HJM-BB-08	535	Dentary	10 YR 5/6 (yellowish brown)	10 YR 5/6 (yellowish brown)	10 YR 5/4 (yellowish brown)
HJM-BB-09	735	Dentary	10 YR 6/4 (light yellowish brown)	10 YR 6/6 (brownish yellow)	10 YR 5/4 (yellowish brown)
HJM-BB-10	910	Dentary	10 YR 5/4 (yellowish brown)	10 YR 5/6 (yellowish brown)	10 YR 5/6 (yellowish brown)
HJM-BB-11	915	Dentary	10 YR 5/4 (yellowish brown)	10 YR 5/4 (yellowish brown)	10 YR 5/4 (yellowish brown)
HJM-BB-12	5047	Dentary	10 YR 6/4 (light yellowish brown)	10 YR 6/4 (light yellowish brown)	10 YR 4/3 (dark brown)
HJM-BB-13	5047	Dentary	10 YR 7/4 (very pale brown)	10 YR 7/4 (very pale brown)	10 YR 5/4 (yellowish brown)
HJM-BB-14	5047	Dentary	10 YR 7/4 (very pale brown)	10 YR 7/4 (very pale brown)	10 YR 5/4 (yellowish brown)
HJM-BB-15	5047	Dentary	10 YR 7/4 (very pale brown)	10 YR 7/4 (very pale brown)	10 YR 5/4 (yellowish brown)
HJM-BB-16	5047	Dentary	10 YR 7/4 (very pale brown)	10 YR 7/4 (very pale brown)	10 YR 4/3 (dark brown)
HJM-BB-17	5340	Dentary	10 YR 7/4 (very pale brown)	10 YR 7/4 (very pale brown)	10 YR 5/4 (yellowish brown)
HJM-BB-18	5340	Dentary	10 YR 7/4 (very pale brown)	10 YR 7/4 (very pale brown)	10 YR 6/4 (light yellowish brown)
HJM-BB-19	5340	Dentary	10 YR 7/3 (very pale brown)	10 YR 7/3 (very pale brown)	10 YR 4/3 (dark brown)
HJM-BB-20	450	Quadrate	10 YR 7/4 (very pale brown)	10 YR 7/4 (very pale brown)	10 YR 5/4 (yellowish brown)
HJM-BB-21	535	Quadrate	10 YR 5/4 (yellowish brown)	10 YR 5/4 (yellowish brown)	10 YR 4/3 (dark brown)
HJM-BB-22	745	Quadrate	10 YR 6/4 (light yellowish brown)	10 YR 6/4 (light yellowish brown)	10 YR 5/4 (yellowish brown)
HJM-BB-23	910	Quadrate	7.5 YR 5/6 (strong brown)	7.5 YR 5/6 (strong brown)	7.5 YR 6/6 (reddish yellow)
HJM-BB-24	915	Quadrate	7.5 YR 5/6 (strong brown)	7.5 YR 5/6 (strong brown)	10 YR 5/6 (yellowish brown)
HJM-BB-25	1510	Quadrate	10 YR 5/4 (yellowish brown)	7.5 YR 5/4 (brown)	7.5 YR 5/6 (strong brown)
HJM-BB-26	5047	Quadrate	10 YR 7/4 (very pale brown)	10 YR 7/4 (very pale brown)	10 YR 6/4 (light yellowish brown)

Sample Number	Calibrated Radiocarbon Intercept (Years BP)	Skeletal Element	Munsell color #1 (on untreated powdered bone)	Munsell color #2 (on NaOH treated powdered bone)	Munsell color #3 (on Hexane: Isopropanol, NaOH, and HCl treated powdered bone)
HJM-BB-27	5047	Quadrate	10 YR 7/4 (very pale brown)	10 YR 7/4 (very pale brown)	10 YR 5/4 (yellowish brown)
HJM-BB-28	5047	Quadrate	10 YR 7/4 (very pale brown)	10 YR 6/4 (light yellowish brown)	10 YR 5/4 (yellowish brown)
HJM-BB-29	5047	Quadrate	10 YR 7/4 (very pale brown)	10 YR 6/4 (light yellowish brown)	10 YR 5/4 (yellowish brown)
HJM-BB-30	5047	Quadrate	10 YR 7/4 (very pale brown)	no sample	no sample
HJM-BB-31	5340	Quadrate	2.5 Y 7/4 (pale yellow)	2.5 Y 7/4 (pale yellow)	2.5 Y 5/4 (light olive brown)
HJM-BB-32	5340	Quadrate	10 YR 6/4 (light yellowish brown)	10 YR 6/4 (light yellowish brown)	10 YR 4/3 (dark brown)
HJM-BB-33	5340	Quadrate	10 YR 7/4 (very pale brown)	10 YR 7/4 (very pale brown)	10 YR 5/4 (yellowish brown)
HJM-BB-34	450	Vomer	10YR 6/4 (light yellowish brown)	10 YR 5/4 (yellowish brown)	10 YR 4/4 (dark yellowish brown)
HJM-BB-35	535	Vomer	10 YR 6/4 (light yellowish brown)	10 YR 6/4 (light yellowish brown)	10 YR 5/3 (brown)
HJM-BB-36	735	Vomer	10 YR 5/6 (yellowish brown)	10 YR 5/6 (yellowish brown)	10 YR 4/3 (dark brown)
HJM-BB-37	910	Vomer	10 YR 6/4 (light yellowish brown)	10 YR 6/4 (light yellowish brown)	10 YR 5/4 (yellowish brown)
HJM-BB-38	915	Vomer	7.5 YR 4/4 (brown/dark brown)	7.5 YR 4/4 (brown/dark brown)	7.5 YR 4/4 (brown /dark brown)
HJM-BB-39	1510	Vomer	10 YR 6/4 (light yellowish brown)	10 YR 5/6 (yellowish brown)	10 YR 5/6 (yellowish brown)
HJM-BB-40	5047	Vomer	2.5 Y 7/4 (pale yellow)	10 YR 7/4 (very pale brown)	10 YR 4/2 (dark brown)
HJM-BB-41	5047	Vomer	2.5 Y 7/4 (pale yellow)	no sample	10 YR 4/3 (dark brown)
HJM-BB-42	5047	Vomer	10 YR 6/4 (light yellowish brown)	10 YR 6/4 (light yellowish brown)	10 YR 5/4 (yellowish brown)
HJM-BB-43	5047	Vomer	10 YR 7/4 (very pale brown)	10 YR 6/4 (light yellowish brown)	10 YR 5/4 (yellowish brown)
HJM-BB-44	5047	Vomer	10 YR 6/4 (light yellowish brown)	10 YR 6/4 (light yellowish brown)	10 YR 4/4 (dark yellowish brown)
HJM-BB-45	5340	Vomer	10 YR 7/4 (very pale brown)	10 YR 7/4 (very pale brown)	10 YR 5/4 (yellowish brown)
HJM-BB-46	5340	Vomer	10 YR 7/4 (very pale brown)	10 YR 7/4 (very pale brown)	10 YR 5/3 (brown)

Sample Number	Calibrated Radiocarbon Intercept (Years BP)	Skeletal Element	Munsell color #1 (on untreated powdered bone)	Munsell color #2 (on NaOH treated powdered bone)	Munsell color #3 (on Hexane: Isopropanol, NaOH, and HCl treated powdered bone)
HJM-BB-47	5340	Vomer	2.5 Y 7/4 (pale yellow)	no sample	10 YR 3/2 (very dark grey brown)
HJM-BB-48	450	Hyomandibular	10 YR 6/4 (light yellowish brown)	10 YR 6/4 (light yellowish brown)	10 YR 5/4 (yellowish brown)
HJM-BB-49	535	Hyomandibular	10 YR 5/4 (yellowish brown)	7.5 YR 5/4 (brown)	7.5 YR 5/4 (brown)
HJM-BB-50	745	Hyomandibular	10 YR 6/4 (light yellowish brown)	10 YR 6/4 (light yellowish brown)	10 YR 5/6 (yellowish brown)
HJM-BB-51	910	Hyomandibular	10 YR 6/4 (light yellowish brown)	10 YR 5/6 (yellowish brown)	10 YR 5/3 (brown)
HJM-BB-52	915	Hyomandibular	10 YR 5/4 (yellowish brown)	10 YR 5/4 (yellowish brown)	10 YR 5/4 (yellowish brown)
HJM-BB-53	1510	Hyomandibular	10 YR 6/4 (light yellowish brown)	10 YR 6/4 (light yellowish brown)	10 YR 5/4 (yellowish brown)
HJM-BB-54	450	Atlas Vertebra	10 YR 6/4 (light yellowish brown)	10 YR 5/4 (yellowish brown)	10 YR 4/4 (dark yellowish brown)
HJM-BB-55	535	Atlas Vertebra	10 YR 5/4 (yellowish brown)	10 YR 5/4 (yellowish brown)	10 YR 4/4 (dark yellowish brown)
HJM-BB-56	745	Atlas Vertebra	10 YR 5/4 (yellowish brown)	10 YR 5/4 (yellowish brown)	10 YR 5/6 (yellowish brown)
HJM-BB-57	910	Atlas Vertebra	10 YR 5/4 (yellowish brown)	10 YR 5/4 (yellowish brown)	10 YR 4/4 (dark yellowish brown)
HJM-BB-58	915	Atlas Vertebra	10 YR 5/4 (yellowish brown)	10 YR 5/4 (yellowish brown)	10 YR 4/4 (dark yellowish brown)
HJM-BB-59	5047	Atlas Vertebra	10 YR 6/4 (light yellowish brown)	10 YR 6/4 (light yellowish brown)	10 YR 4/3 (dark brown)
HJM-BB-60	5047	Atlas Vertebra	10 YR 7/4 (very pale brown)	10 YR 7/4 (very pale brown)	10 YR 5/4 (yellowish brown)
HJM-BB-61	5047	Atlas Vertebra	10 YR 6/4 (light yellowish brown)	10 YR 6/4 (light yellowish brown)	10 YR 5/4 (yellowish brown)
HJM-BB-62	5047	Atlas Vertebra	10 YR 7/4 (very pale brown)	10 YR 7/4 (very pale brown)	10 YR 5/3 (brown)
HJM-BB-63	5047	Atlas Vertebra	10 YR 7/3 (very pale brown)	10 YR 6/4 (light yellowish brown)	10 YR 4/3 (dark brown)
HJM-BB-64	5047	Atlas Vertebra	10 YR 7/4 (very pale brown)	10 YR 7/4 (very pale brown)	10 YR 5/4 (yellowish brown)
HJM-BB-65	5340	Atlas Vertebra	10 YR 7/4 (very pale brown)	10 YR 7/4 (very pale brown)	10 YR 5/4 (yellowish brown)
HJM-BB-66	5340	Atlas Vertebra	10 YR 6/4 (light yellowish brown)	10 YR 6/4 (light yellowish brown)	10 YR 5/4 (yellowish brown)

Sample Number	Calibrated Radiocarbon Intercept (Years BP)	Skeletal Element	Munsell color #1 (on untreated powdered bone)	Munsell color #2 (on NaOH treated powdered bone)	Munsell color #3 (on Hexane: Isopropanol, NaOH, and HCl treated powdered bone)
HJM-BB-67	450	Maxilla	10 YR 5/4 (yellowish brown)	10 YR 5/4 (yellowish brown)	10 YR 5/6 (yellowish brown)
HJM-BB-68	535	Maxilla	10 YR 5/4 (yellowish brown)	10 YR 5/4 (yellowish brown)	10 YR 5/6 (yellowish brown)
HJM-BB-69	735	Maxilla	10 YR 6/4 (light yellowish brown)	10 YR 6/4 (light yellowish brown)	10 YR 5/4 (yellowish brown)
HJM-BB-70	910	Maxilla	10 YR 5/6 (yellowish brown)	10 YR 5/6 (yellowish brown)	10 YR 5/6 (yellowish brown)
HJM-BB-71	915	Maxilla	10 YR 7/4 (very pale brown)	10 YR 7/4 (very pale brown)	10 YR 5/4 (yellowish brown)
HJM-BB-72	5047	Maxilla	10 YR 7/4 (very pale brown)	10 YR 7/4 (very pale brown)	10 YR 5/4 (yellowish brown)
HJM-BB-73	5047	Maxilla	10 YR 7/4 (very pale brown)	10 YR 6/4 (light yellowish brown)	10 YR 6/4 (light yellowish brown)
HJM-BB-74	5047	Maxilla	10 YR 7/4 (very pale brown)	10 YR 7/4 (very pale brown)	10 YR 7/4 (very pale brown)
HJM-BB-75	5047	Maxilla	10 YR 7/4 (very pale brown)	10 YR 7/4 (very pale brown)	10 YR 7/4 (very pale brown)
HJM-BB-76	5047	Maxilla	10 YR 7/4 (very pale brown)	10 YR 7/4 (very pale brown)	10 YR 7/4 (very pale brown)
HJM-BB-77	5340	Maxilla	10 YR 6/4 (light yellowish brown)	10 YR 6/4 (light yellowish brown)	10 YR 6/4 (light yellowish brown)
HJM-BB-78	5340	Maxilla	10 YR 7/4 (very pale brown)	no sample	10 YR 7/4 (very pale brown)

Appendix F: Amino acid sequence of Atlantic cod (*Gadus morhua*) and quality control indicator calculations. Amino acid sequence from Arnesen and Gildberg (2006).

Appendix F.1. Amino acid sequence of Atlantic cod. Adapted from Arnesen and Gildberg (2006).

Atlantic cod (*Gadus morhua*): Amino Acid Sequence			
Amino Acid	**Residues per 1000**	**Molecular Weight**	**Total # in 1000 Residues**
Alanine (Ala)	103	89	9167
Arginine (Arg)	54	174	9396
Aspartic Acid (Asp)	53	133	7049
Glutamic Acid (Glu)	73	147	10731
Glycine (Gly)	358	75	26850
Histidine (His)	11	155	1705
Hydroxylysine	0	131	0
Hydroxyproline	56	131	7336
Isoleucine (Ile)	12	131	1572
Leucine (Leu)	21	131	2751
Lysine (Lys)	25	162	4050
Methionine (Met)	16	149	2384
Phenylalanine(Phe)	12	165	1980
Proline (Pro)	95	115	10925
Serine (Ser)	63	105	6615
Threonine (Thr)	24	119	2856
Tyrosine (Tyr)	5	181	905
Valine (Val)	18	117	2106
Total	**999**		**108378**

Appendix F.2. Atlantic cod quality indicator calculations.

Atlantic cod (*Gadus morhua*) Quality Indicator Calculations	
Number of Hydrogen (H)atoms removed with peptide bond formation (# of peptide bonds x 2)	**2000**
Number of Oxygen (O) atoms removed with peptide bond formation (# of peptide bonds x 1)	**1000**
Weight of H atoms removed (# of H atoms 2000 x 1.00794)	**2015.88**
Weight of O atoms removed (1000 x 15.9994)	**15999.4**
New weight of 1000 residue collagen molecule with peptide bonds formed (weight of individual amino acid minus weight of H atoms removed + weight of O atoms removed)	**90362.72**

Appendix F.3. Atlantic Cod atomic C: N calculations.

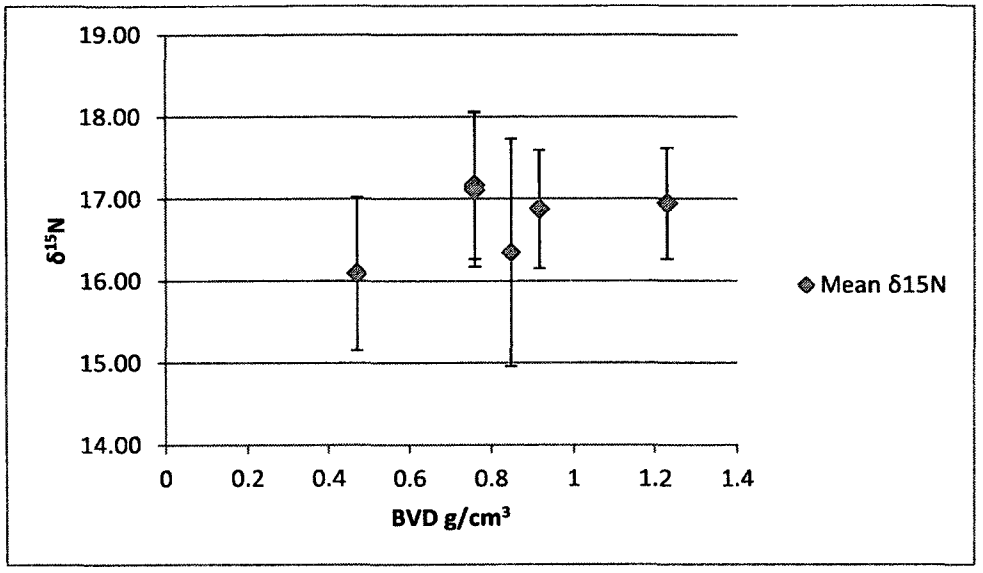
Amino Acid Sequence (*Gadus morhua*) and Quality Control Indicator Calculations						
Amino Acid	**Residues per 1000**	**Total C atoms**	**C Weight (c atoms x 12.0107)**	**Total N atoms**	**N Weight (N atoms x 14.00674)**	**C: N atoms (Total C atoms / Total N atoms)**
Alanine (Ala)	103	309	3711.306	103	1442.694	3
Arginine (Arg)	54	324	3891.467	216	3025.456	1.5
Aspartic Acid (Asp)	53	212	2546.268	53	742.3572	4
Glutamic Acid (Glu)	73	365	4383.906	73	1022.492	5
Glycine (Gly)	358	716	8599.661	358	5014.413	2
Histidine (His)	11	66	792.7062	33	462.2224	2
Hydroxylysine	0	0	0	0	0	0
Hydroxyproline	56	280	3362.996	56	784.3774	5
Isoleucine (Ile)	12	72	864.7704	12	168.0809	6
Leucine (Leu)	21	126	1513.348	21	294.1415	6
Lysine (Lys)	25	150	1801.605	50	700.337	3
Methionine (Met)	16	80	960.856	16	224.1078	5
Phenylalanine (Phe)	12	108	1297.156	12	168.0809	9
Proline (Pro)	95	475	5705.083	95	1330.64	5
Serine (Ser)	63	189	2270.022	63	882.4246	3
Threonine (Thr)	24	96	1153.027	24	336.1618	4
Tyrosine (Tyr)	5	45	540.4815	5	70.0337	9
Valine (Val)	18	90	1080.963	18	252.1213	5
Total	**999**	**3703**	**44475.62**	**1208**	**16920.14**	**3.06539**

Appendix F.4. Atlantic cod quality indicator acceptable ranges.

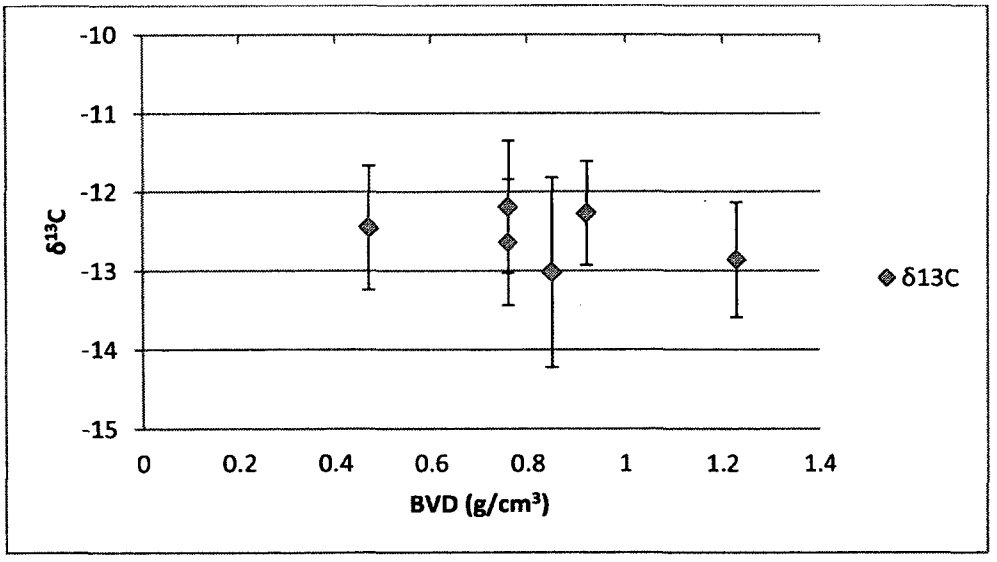
Quality Control Indicator Calculations	%C by Weight Acceptable Range (x100)	%N by Weight Acceptable Range (x100)	Peptide Bonds
Weight percent for 1000 amino acids (total weight = 108378)	0.410375	0.156122	hydrolyzed
Weight percent for 1000 amino acid residues (amino acid weight minus weight of an H_2O per peptide bond) (total weight = 90362.72)	0.49219	0.187247	Unhydrolyzed

Amino Acid sequence of Type I collagen alpha 1 and alpha 2 chains from UniProt. Amino acid molecular weight from Nelson and Cox (2005). Number of hydrolysine and hydroxyproline residues from Bhatnager (2006). Atomic mass of carbon and nitrogen from Masterson and Hurley (2004). Number of carbon and nitrogen atoms in amino acids from Ambrose (1993). Number of lysine and proline residues was reduced from number coded in UniPort by the number of hydroxylated in Bhatnager (2006). Residues per 1000 (converted from moles per 100 moles amino acid by multiplying by 100) from Arnesen and Gildberg (2006).

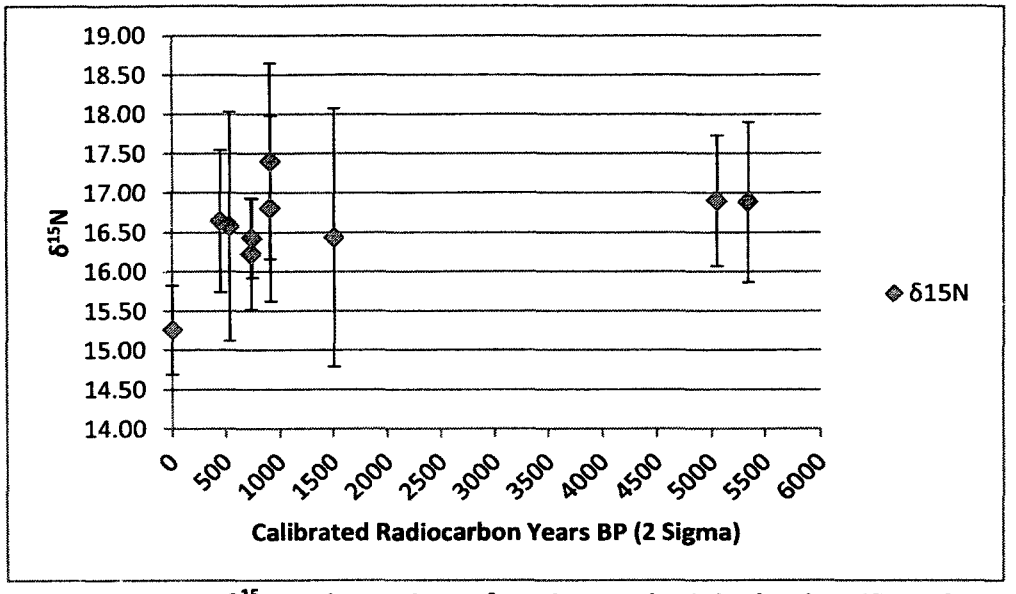
Appendix G: $\delta^{15}N$ and $\delta^{13}C$ values by BVD, mean completeness %, and Radiocarbon years BP.



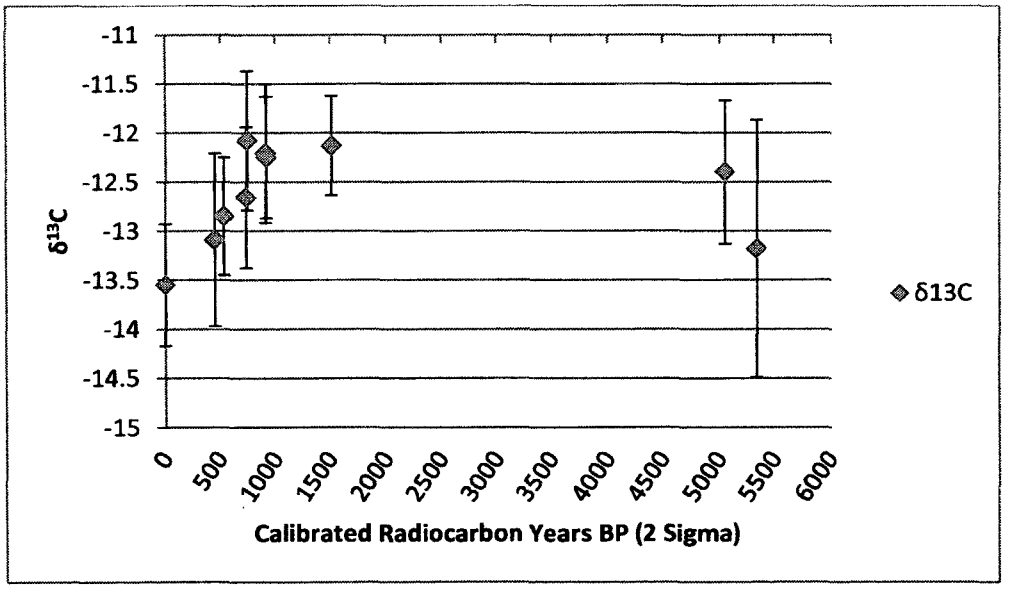
Appendix G.1. Mean $\delta^{15}N$ and SD values of Mink Island Pacific cod samples aggregated by BVD.



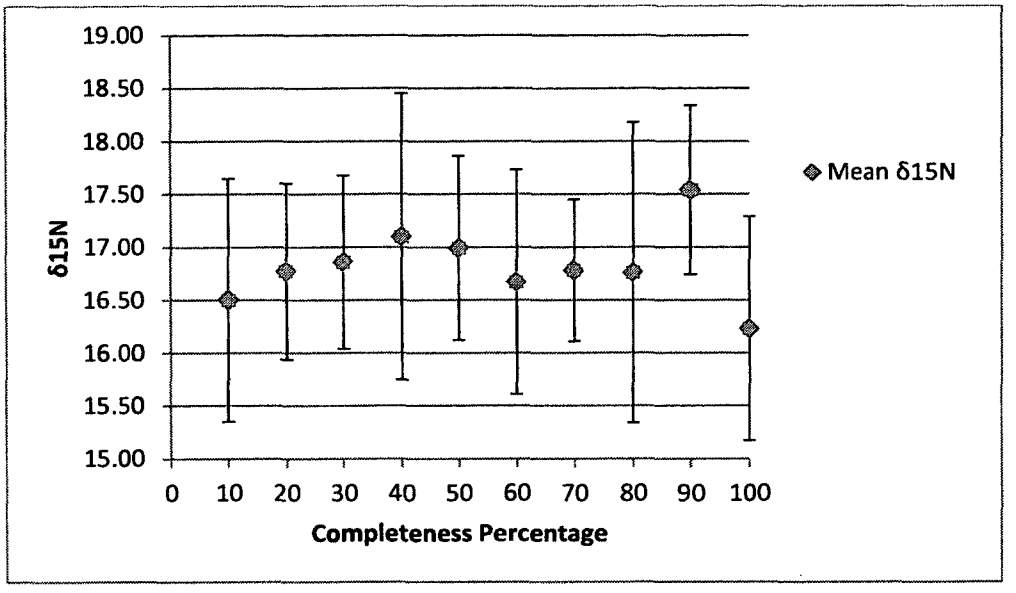
Appendix G.2. Mean $\delta^{13}C$ and SD values of Mink Island Pacific cod samples aggregated by BVD.



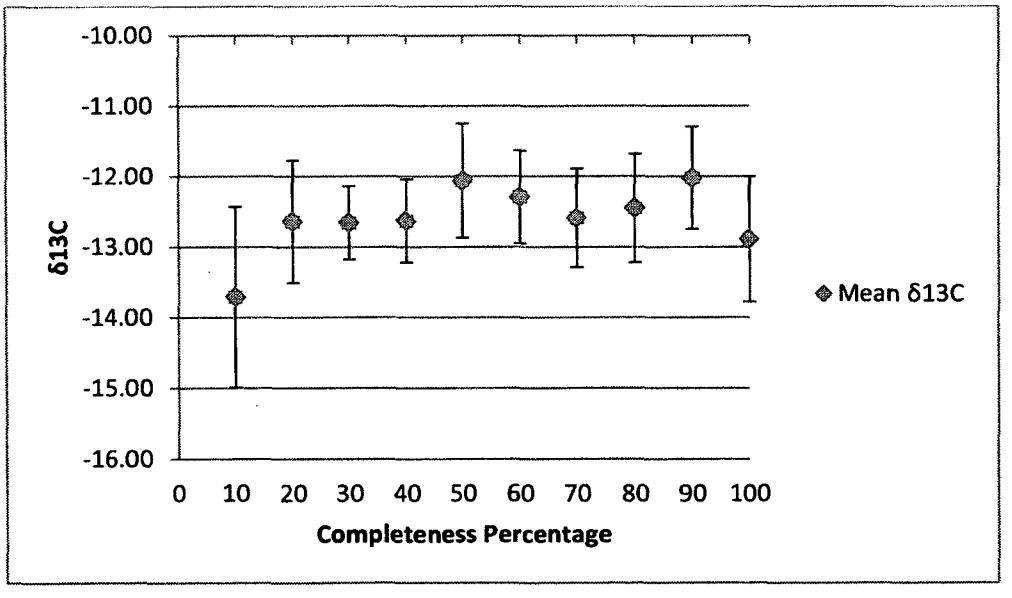
Appendix G.3. Mean $\delta^{15}N$ and SD values of modern and Mink Island Pacific cod samples aggregated by calibrated radiocarbon years BP.



Appendix G.4. Mean $\delta^{13}C$ and SD values of modern and Mink Island Pacific cod samples aggregated by calibrated radiocarbon years BP.



Appendix G.5. Mean $\delta^{15}N$ and SD values of Mink Island Pacific cod samples aggregated by completeness %.



Appendix G.6. Mean $\delta^{13}C$ and SD values of Mink Island Pacific cod samples aggregated by completeness %.

Appendix H: MNE values of family-level skeletal elements

Appendix H.1. MNE values of family-level skeletal elements from HF.5 (640-510 cal. BP).

HF.5 (640-510 cal. BP) MNE Values								
Skeletal Element	**Clupeidae**	**Cottidae**	**Gadidae**	**Hexagrammidae**	**Osmeridae**	**Pleuronectidae**	**Salmonidae**	**Sebastidae**
Articular		14	22	1		1	1	
Basibranchial		1						
Basioccipital		11	17					1
Basipterygium			5			1	72	
Branchiostegal Ray		46	71			6		3
Caudal Bony Plate							19	
Caudal Fin						1		
Ceratobranchial		10	16			2		
Ceratohyal		8	11			1	2	
Circumorbital							1	
Cleithrum		4	15			1	10	
Coracoid		5					17	
Dentary		16	42	1		3		3
Dorsal Spine		6						
Ectopterygoid		5	6				1	
Epibranchial		4	43	1		1		
Epihyal		9	11					
Epural						1		
Ethmoid		3						
Exoccipital		11	3					
Expanded Haemal Spine							6	
Frontal			3					
Hyomandibular		20	10			1	1	
Hypobranchial		3	17				1	
Hypohyal		8	10			1		
Hypural			5					
Interhaemal Spine						1		
Interhyal		3	7				4	
Interopercle		8	8					
Lachrymal		2	5					
Maxilla		15	23	3		3	1	
Mesethmoid			7					
Mesocoracoid							17	
Mesopterygoid			9					
Metapterygoid			2					
Nasal			18					

HF.5 (640-510 cal. BP) MNE Values								
Skeletal Element	**Clupeidae**	**Cottidae**	**Gadidae**	**Hexagrammidae**	**Osmeridae**	**Pleuronectidae**	**Salmonidae**	**Sebastidae**
Opercle		20	15			2	1	1
Opisthotic			7					
Otolith			8					
Palatine		6	18					
Parasphenoid		6	11					
Parietal		5						
Pharyngeal Plate		7	18					
Pharyngobranchial		2	26					
Post Cleithrum		4	10				22	1
Post Temporal		8	27			1	5	
Prefrontal			7					
Premaxilla		15	37	1		6		2
Preopercle		11	10	1			1	
Prootic		2	2					
Pterotic		3	8					
Pterygiophore			2					
Quadrate		27	19	1		2	2	
Radial		2				1	10	
Retroarticular			5					
Scapula		4					21	1
Sphenotic		19	10					
Subopercle		9	5					
Supracleithrum		13	20			5		
Supraoccipital			1					
Symplectic			6					
Urohyal		1				1		
Vertebrae	333	279	844		3	54	1914	
Vomer		12	24			1		
Total HF.5	**333**	**667**	**1526**	**9**	**3**	**97**	**2129**	**12**

Appendix H.2. MNE values of family-level skeletal elements from UM I (750-455 cal. BP).

UM I (750-455 cal. BP) MNE Values						
Skeletal Element	**Clupeidae**	**Cottidae**	**Gadidae**	**Hexagrammidae**	**Pleuronectidae**	**Salmonidae**
Basibranchial					3	
Basioccipital		1	1			
Basipterygium						2
Branchiostegal Ray		7	2			
Caudal Bony Plate						2
Ceratohyal		3				
Cleithrum		1				3
Coracoid		1				3
Dentary		4	2			
Dorsal Spine		1				
Epihyal		1	1			
Ethmoid						
Frontal		2				
Gill Raker						
Hyomandibular		1				
Hypobranchial			2			
Hypohyal			3			
Hypural						1
Interhyal			1		1	1
Interneural		1	2		1	
Maxilla		5				
Mesethmoid						
Mesocoracoid						2
Mesopterygoid		3				
Nasal			1			
Opercle		2	2			
Palatine		3				
Parasphenoid		1				
Pharyngeal Plate			1			
Pharyngobranchial			1			
Post Cleithrum		3				3
Post Temporal						2
Prefrontal		1	1			
Premaxilla		3				
Preopercle		2	1			
Prootic		2				
Quadrate		3				
Radial		1				
Retroarticular			1			
Scapula						4
Subopercle		1				
Supracleithrum		4				3
Symplectic			1			

UM I (750-455 cal. BP) MNE Values						
Skeletal Element	**Clupeidae**	**Cottidae**	**Gadidae**	**Hexagrammidae**	**Pleuronectidae**	**Salmonidae**
Urohyal			1			
Vertebrae	28	44	12	1	3	11
Vomer			1			
Total UM I	**28**	**101**	**37**	**1**	**8**	**37**

Appendix H.3 MNE values of family-level skeletal elements from UM II (1000-750 cal. BP).

UM II (1000-750 cal. BP) MNE Values							
Skeletal Element	**Clupeidae**	**Cottidae**	**Gadidae**	**Hexagrammidae**	**Pleuronectidae**	**Salmonidae**	**Sebastidae**
Articular		6	12		1		
Basibranchial					1		
Basioccipital		3	3				
Basipterygium						1	
Branchiostegal Ray		52	75		24		
Caudal Bony Plate						1	
Caudal Fin					2		
Ceratobranchial		1	12				
Ceratohyal		6	4				
Cleithrum			3			2	
Coracoid						1	
Dentary		13	15				1
Ectopterygoid			1				
Epibranchial		3	19				
Epihyal		8	10				
Exoccipital		2	1				
Frontal			1				
Hyomandibular		2	9				
Hypobranchial			4		1		
Hypohyal		3	7				
Interhyal		7	5				
Interopercle		1	5				
Lachrymal		4	1				
Maxilla		2	5				
Mesocoracoid						2	
Nasal			1				
Opercle		2	2				
Otolith			7				
Palatine		3	6		1		
Parasphenoid		3	5				
Parietal		1					
Pharyngeal Plate		1	21				
Pharyngobranchial			16				
Post Cleithrum		3				1	
Post Temporal			7				
Prefrontal			1				
Premaxilla		4	7				

Preopercle		5	7				
Quadrate		5	12				
Radial		1				1	1
Retroarticular		2	11				
Scapula						1	
Sphenotic		5	4				
Subopercle		5	1				
Supracleithrum			3				
Symplectic			1				
Urohyal					1		
Vertebrae	7	167	352	3	11	63	1
Vomer		1	5				
Total UM II	**7**	**321**	**661**	**3**	**42**	**73**	**3**

Appendix H.4. MNE values of family-level skeletal elements from UM III (1600-1000 cal. BP).

UM III (1600-1000 cal. BP) MNE Values							
Skeletal Element	**Clupeidae**	**Cottidae**	**Gadidae**	**Hexagrammidae**	**Pleuronectidae**	**Salmonidae**	**Sebastidae**
Articular		4	9		5		
Basibranchial			1			1	
Basioccipital		4	5		1		
Basipterygium		31	3			6	
Branchiostegal Ray		3	70	1	19	1	
Caudal Bony Plate						2	
Caudal Fin					7		
Ceratobranchial			9				
Ceratohyal		4	4				
Cleithrum		2	8		1	3	
Coracoid		6				2	
Dentary			14	1	2		
Ectopterygoid		1	2				
Epibranchial			19		2		
Epihyal		2	7				
Exoccipital		1	2				
Expanded Haemal Spine						2	
Frontal			2				
Hyomandibular		2	4		1	4	
Hypobranchial		1	11		2		
Hypohyal		2	1		1	1	
Hypural			1			1	
Interhaemal Spine					2		
Interhyal		3	4		2	3	
Interopercle		1	2				
Lachrymal		1					
Maxilla		2	8		1		
Mesethmoid		1	2				
Mesopterygoid		1					
Nasal			1				
Opercle		3	4				
Otolith			10		1		
Palatine		2	4				
Parasphenoid		1	3				
Parietal			1				
Pharyngeal Plate		2	13		1		
Pharyngobranchial					1		

Post Cleithrum		2				1	
Post Temporal					2	1	
Prefrontal							
Premaxilla		5	15	3	2		
Preopercle		5	3		2		
Prootic			1				
Pterotic		1	3		1		
Quadrate		5	10	1	3		
Radial		1					
Retroarticular			1				
Rib						1	
Scapula						3	
Sphenotic		2	5				
Subopercle			1				
Supracleithrum		2	5		1	1	
Supraoccipital			1				
Urohyal			3				
Vertebrae	40	225	347	1	64	103	21
Vomer		5	5		3		
Total UM III	**40**	**333**	**624**	**7**	**127**	**136**	**21**

Appendix H.5. MNE values of family-level skeletal elements from LM I(5400-4100 cal. BP).

LM I (5400-4100 cal. BP) MNE Values							
Skeletal Element	**Clupeidae**	**Cottidae**	**Gadidae**	**Hexagrammidae**	**Pleuronectidae**	**Salmonidae**	**Sebastidae**
Articular		21	35	4	7		6
Basibranchial			3		2		
Basihyal					4		
Basioccipital		44	16		4		
Basipterygium					1		
Branchiostegal Ray		128	310		15		1
Caudal Bony Plate						1	
Caudal Fin					3		
Ceratobranchial			2		2		
Ceratohyal		2	4				
Cleithrum		3	2		1		
Dentary		55	54		4		2
Dorsal Spine		7					
Ectopterygoid		5	2		18		
Epibranchial		7	41		5		
Epihyal		38	19		1		
Exoccipital		15			3		
Expanded Haemal Spine						2	
Hyomandibular		28	4		3	1	
Hypobranchial			5		9	1	1
Hypohyal		6	10		10		
Interhaemal Spine					10		
Interhyal		26	15		3		
Interneural			1				
Interopercle		6	1				
Lachrymal		3					
Maxilla		21	46		7		3
Mesethmoid		3					
Mesopterygoid		1	2				
Opercle		6	1				
Opisthotic					1		
Otolith			7				
Palatine		9	17		7		
Parasphenoid		24	12				
Parietal		4	1				
Pharyngeal Plate		2	28		5		
Pharyngobranchial		2	42		3		
Post Cleithrum		21	3			2	
Post Temporal			21		8		
Prefrontal					1		
Premaxilla		31	88	3	12		2
Preopercle		3					

LM I (5400-4100 cal. BP) MNE Values							
Skeletal Element	**Clupeidae**	**Cottidae**	**Gadidae**	**Hexagrammidae**	**Pleuronectidae**	**Salmonidae**	**Sebastidae**
Prootic			2		3		
Pterotic		2	5				
Pterygiophore		1					
Quadrate		62	57	7	13	1	1
Radial		1			1		
Retroarticular		3	11				
Rib						1	
Scapula					1		
Sphenotic		12	6				
Subopercle		2	1				
Supracleithrum		7	15		10		
Urohyal		11	4		2		
Vertebrae	8	895	1183	48	200	547	1
Vomer		35	39	2	5		2
Total LM I	**8**	**1552**	**2115**	**64**	**384**	**556**	**19**

Appendix H.6. MNE values of family-level skeletal elements from LM II (6700-5400 cal. BP).

LM II (6700-5400 cal. BP) MNE Values							
Skeletal Element	**Clupeidae**	**Cottidae**	**Gadidae**	**Hexagrammidae**	**Pleuronectidae**	**Salmonidae**	**Sebastidae**
Articular		6	9	3	18		5
Basibranchial		1	1				
Basihyal					3		
Basioccipital		2	2	1	32		
Basipterygium					3		
Branchiostegal Ray		6	14		4		
Caudal Bony Plate						1	
Ceratobranchial					2		
Ceratohyal			2				
Cleithrum			1		7		
Dentary		4	8		24		
Ectopterygoid			2		12		
Epibranchial			3		8		
Epihyal		3	1		8		
Ethmoid					1		
Exoccipital					11		
Frontal		1	1		3		
Hyomandibular		3			14		
Hypobranchial			1		6		
Hypohyal			1		17		
Interhaemal Spine					22		
Interhyal		1	1		3		
Interopercle		1					
Maxilla		3	5		18		3
Mesopterygoid		1					
Nasal		1					
Opercle					1		
Opisthotic					1		
Otolith			2				
Palatine			3		8		
Parasphenoid		1	3		5		
Parietal					1		
Pharyngeal Plate			1				
Pharyngobranchial			3		6		
Post Temporal			4		16		
Prefrontal		1			1		
Premaxilla		2	5	3	21		
Preopercle			1		1		

LM II (6700-5400 cal. BP) MNE Values							
Skeletal Element	***Clupeidae***	***Cottidae***	***Gadidae***	***Hexagrammidae***	***Pleuronectidae***	***Salmonidae***	***Sebastidae***
Prootic					11		
Pterotic		1			2		
Pterygiophore					1		
Quadrate		6	7	7	23		
Retroarticular			2				
Scapula					1		
Sphenotic		1	3		1		
Supracleithrum			1		13		
Urohyal					25		
Vertebrae	4	155	158	10	729	133	
Vomer			5		16		
Total LM II	**4**	**200**	**250**	**24**	**1099**	**134**	**8**

Appendix I: Pacific cod quadrate #3 measurements (from Orchard, 2003) and reconstructed fork Lengths.

Pacific cod (*Gadus macrocephalus*) Quadrate		
Temporal/ Cultural Zone	**#3 measurement (mm)**	**Fork Length (cm)**
HF.5 (640-510 cal. BP)	8.25	57.45
	9.65	65.41
	8.55	59.15
	10.35	69.39
	8.60	59.44
	9.80	66.26
	9.40	63.99
	9.85	66.55
	10.70	71.38
	11.80	77.64
	8.65	59.72
	8.85	60.86
	9.90	66.83
UM I (750-455 cal. BP)	9.35	63.70
	7.80	54.89
	12.70	82.76
	12.55	81.90
	10.80	71.95
	12.75	83.04
	12.75	83.04
	10.40	69.67
	10.15	68.25
	13.40	86.74
	12.00	78.78
	9.55	64.84
	10.05	67.68
	10.60	70.81
	10.35	69.39
UM II (1000-750 cal. BP)	8.70	60.00
	10.85	72.23
	9.85	66.55
	10.45	69.96
	12.00	78.78
	9.85	66.55
	9.65	65.41
	18.05	113.19
	10.20	68.54
	9.95	67.11
	12.25	80.20
	10.40	69.67
	12.70	82.76
	10.05	67.68

Pacific cod (*Gadus macrocephalus*) Quadrate		
Temporal/ Cultural Zone	**#3 measurement (mm)**	**Fork Length (cm)**
	8.80	60.57
	10.05	67.68
	9.25	63.13
	9.10	62.28
	8.75	60.29
	8.05	56.31
	8.15	56.88
	12.80	83.33
	9.55	64.84
	9.40	63.99
UM III (1600-1000 cal. BP)	9.40	63.99
	10.10	67.97
	10.45	69.96
	10.45	69.96
	10.00	67.40
	9.35	63.70
	9.40	63.99
	7.30	52.04
	10.25	68.74
	9.20	62.85
	9.20	62.85
	8.25	57.45
LM I (5400-4100 cal. BP)	11.15	73.94
	5.75	43.23
	10.15	68.25
	13.10	85.03
	10.60	70.81
	9.65	65.41
	9.65	65.41
	10.30	69.11
	8.30	57.73

Appendix J: Shannon-Wiener Index of Heterogeneity associated with the Mink Island fish bone assemblages.. Logs are natural logarithms.

Appendix J.1. Shannon-Wiener Index of Heterogeneity calculations from HF.5 (640-510 cal. BP).

Taxon	HF.5 (640-510 cal. BP) NISP	Proportion (P)	Log of P	p(log P)
Atheresthes	1	0.00023	-8.377	-0.002
Clupea	344	0.07795	-2.552	-0.199
Eleginus	742	0.16406	-1.808	-0.297
Gadus	856	0.19397	-1.640	-0.318
Hemilepidotus	283	0.06413	-2.747	-0.176
Hexagrammos	2	0.00045	-7.706	-0.003
Hippoglossus	19	0.00431	-5.447	-0.023
Lepidopsetta	1	0.00023	-8.377	-0.002
Myoxocephalus	16	0.00363	-5.619	-0.020
Oncorhynchus	2130	0.48266	-0.728	-0.352
Ophiodon	1	0.00023	-8.377	-0.002
Platichthys	2	0.00045	-7.706	-0.003
Pleurogrammus	4	0.00091	-7.002	-0.006
Sebastes	8	0.00181	-6.314	-0.011
Thaleichthys	3	0.00068	-7.293	-0.005
Theragra	1	0.00023	-8.377	-0.002
Total	**4413**			**-1.422**

Appendix J.2. Shannon-Wiener Index of Heterogeneity calculations from UM I (750-455 cal. BP).

Taxon-Genus	UM I (750-455 cal. BP) NISP	Proportion (P)	Log of P	p(log P)
Clupea	28	0.17073	-1.768	-0.302
Gadus	29	0.17683	-1.733	-0.306
Hemilepidotus	49	0.29878	-1.208	-0.361
Hexagrammos	1	0.0061	-5.099	-0.031
Limanda	3	0.01829	-4.001	-0.073
Myoxocephalus	11	0.06707	-2.702	-0.181
Oncorhynchus	43	0.2622	-1.339	-0.35
Total	**164**			**-1.604**

Appendix J.3. Shannon-Wiener Index of Heterogeneity calculations from UM II (1000-750 cal. BP).

Taxon-Genus	UM II (1000-750 cal. BP) NISP	Proportion (P)	Log of P	p(log P)
Clupea	7	0.00706	-4.953	-0.035
Gadus	741	0.74698	-0.292	-0.391
Hemilepidotus	132	0.13306	-2.017	-0.268
Hippoglossoides	5	0.00504	-5.29	-0.027
Isopsetta	5	0.00504	-5.29	-0.027
Lepidopsetta	1	0.00101	-6.898	-0.007
Limanda	2	0.00202	-6.205	-0.013
Myoxocephalus	16	0.01613	-4.127	-0.067
Oncorhynchus	73	0.07359	-2.609	-0.192
Pleurogrammus	3	0.00302	-5.802	-0.018
Sebastes	3	0.00302	-5.802	-0.018
Theragra	4	0.00403	-5.514	-0.022
Total	**992**			**-1.085**

Appendix J.4. Shannon-Wiener Index of Heterogeneity calculations from UM III (1600-1000 cal. BP).

Taxon-Genus	UM III (1600-1000 cal. BP) NISP	Proportion (P)	Log of P	p(log P)
Atheresthes	3	0.00247	-6.004	-0.015
Clupea	40	0.03287	-3.415	-0.112
Eleginus	3	0.00247	-6.004	-0.015
Gadus	763	0.62695	-0.467	-0.293
Hemilepidotus	87	0.07149	-2.638	-0.189
Hexagrammos	3	0.00247	-6.004	-0.015
Hippoglossoides	15	0.01233	-4.396	-0.054
Hippoglossus	20	0.01643	-4.109	-0.068
Isopsetta	2	0.00164	-6.413	-0.011
Lepidopsetta	25	0.02054	-3.885	-0.08
Limanda	20	0.01643	-4.109	-0.068
Myoxocephalus	14	0.0115	-4.465	-0.051
Oncorhynchus	137	0.11257	-2.184	-0.246
Platichthys	1	0.00082	-7.106	-0.006
Pleurogrammus	6	0.00493	-5.312	-0.026
Sebastes	21	0.01726	-4.059	-0.07
Thaleichthys	4	0.00329	-5.717	-0.019
Theragra	53	0.04254	-3.157	-0.134
Total	**1217**			**-1.471**

Appendix J.5. Shannon-Wiener Index of Heterogeneity calculations from LM I (5400-4100 cal. BP).

Taxon-Genus	LM I (5400-4100 cal. BP) NISP	Proportion (P)	Log of P	p(log P)
Atheresthes	4	0.00094	-6.97	-0.007
Citharichthys	3	0.00071	-7.25	-0.005
Clupea	9	0.00212	-6.156	-0.013
Gadus	2356	0.55624	-0.587	-0.326
Glyptocephalus	5	0.00118	-6.742	-0.008
Hemilepidotus	689	0.16246	-1.817	-0.295
Hexagrammos	32	0.00755	-4.886	-0.037
Hippoglossoides	87	0.02051	-3.887	-0.08
Hippoglossus	16	0.00377	-5.581	-0.021
Isopsetta	15	0.00354	-5.644	-0.02
Lepidopsetta	72	0.01698	-4.076	-0.069
Leptocottus	1	0.00024	-8.335	-0.002
Limanda	22	0.00519	-5.261	-0.027
Myoxocephalus	149	0.03513	-3.349	-0.118
Oncorhynchus	529	0.12473	-2.082	-0.26
Ophiodon	18	0.00424	-5.463	-0.023
Platichthys	38	0.00896	-4.715	-0.042
Pleurogrammus	14	0.0033	-5.714	-0.019
Pleuronectes	13	0.00307	-5.786	-0.018
Sebastes	25	0.00589	-5.134	-0.03
Theragra	144	0.03395	-3.383	-0.115
Total	**4241**			**-1.535**

Appendix J.6. Shannon-Wiener Index of Heterogeneity calculations from LM II (6700-5400 cal. BP).

Taxon-Genus	LM II (6700-5400 cal. BP) NISP	Proportion (P)	Log of P	p(log P)
Atheresthes	2	0.00138	-6.586	-0.008
Citharichthys	1	0.00069	-7.279	-0.005
Clupea	4	0.00275	-5.896	-0.016
Gadus	213	0.14669	-1.919	-0.282
Glyptocephalus	12	0.00826	-4.796	-0.04
Hemilepidotus	59	0.04063	-3.203	-0.13
Hexagrammos	19	0.01309	-3.477	-0.046
Hippoglossoides	120	0.08264	-2.493	-0.206
Hippoglossus	14	0.00964	-4.642	-0.045
Isopsetta	193	0.13292	-2.018	-0.268
Lepidopsetta	374	0.25758	-1.356	-0.349
Limanda	39	0.02686	-3.617	-0.097
Myoxocephalus	47	0.03237	-3.431	-0.111
Oncorhynchus	134	0.09229	-2.383	-0.22
Ophiodon	11	0.00758	-4.882	-0.037
Platichthys	114	0.07851	-2.545	-0.12
Pleurogrammus	1	0.00069	-7.279	-0.005
Pleuronectes	35	0.0241	-3.726	-0.09
Sebastes	9	0.0062	-5.083	-0.032
Theragra	51	0.03512	-3.349	-0.118
Total	**1452**			**-2.225**

Appendix K. Permissions

---------- Forwarded message ----------
From: **Schaaf, Jeanne** <jeanne_schaaf@nps.gov>
Date: Fri, Mar 29, 2013 at 2:11 PM
Subject: photo permissions
To: Holly McKinney <hjmckinney@alaska.edu>

Holly,

You have my permission to use the following NPS photographs and figures in your dissertation.

Figure 4.4. Photograph of Mink Island Upper Midden Profile.
Figure 4.5. Planview of the Mink Island site (from Hilton, 2000-unpublished NPS Upper Midden Report).
Figure 4.6. Photograph of the Mink Island Lower Midden Profile.
Figure 4.8. Profile of the Mink Island Upper Midden Excavation Area A (from Hilton, 2000- unpublished NPS Upper Midden Report).
Figure 4.9. Profile and planview of Excavation Area C (House Feature 5) (from Hilton, 2000-unpublished NPS Upper Midden Report).
Figure 8.9. Immature Sea Lion Scapula and tools from an occupation on the white tephra from a volcan eruption, 6500 BP.
Figure 8.10. Red ochre-stained shelter at Mink Island occupied 5350 BP.
Figure 8.11. Extensive shell and bone accumulation associated with Upper Midden (Stages III and IV).

Sincerely,

Jeanne Schaaf

Re: Mink Island Figures

tenn0037@umn.edu
Tue 12/04/12 1:52 PM
Holly McKinney (happyinak@hotmail.com)

Holly,

[redacted]. Yes, please do use the figures from my dissertation. [redacted]

[redacted]

You have my permission to use figures from my dissertation (pp.169, Figure 7.2, Mink Island planview; pp. 173, Figure 7.3, Lower Midden profile) in your dissertation.

[redacted]

[redacted]

Dave Tennessen

UNIVERSITY of ALASKA

Drawing

alstelton <alsart1@bwig.net> Mon, Apr 1, 2013 at 7:15 AM
To: hjmckinney@alaska.edu

Holly, You have my permission to use my drawing (Figure 4.11 Composite fishhooks, spreader bar, and grooved stone for capturing marine fishes) in your dissertation. Sincerely, Al Stelton.